Control of Powder Properties for Food Materials by Fine Grinding with Various Pulverizers

BY
Dr. Satoshi Akiyama
Manager
Nisshin Seifun Group Inc.

Dr. Carl K. Ishito
General Manager
Nisshin Engineering Inc.

* Powder & Bulk Solids 2006 (29th) Technical Session S21

* Presented date: May 11, 2006 (Thu) 9:00-10:15AM

* Place: Donald E. Stephens Convention Center, IL USA

NISSHIN ENGINEERING

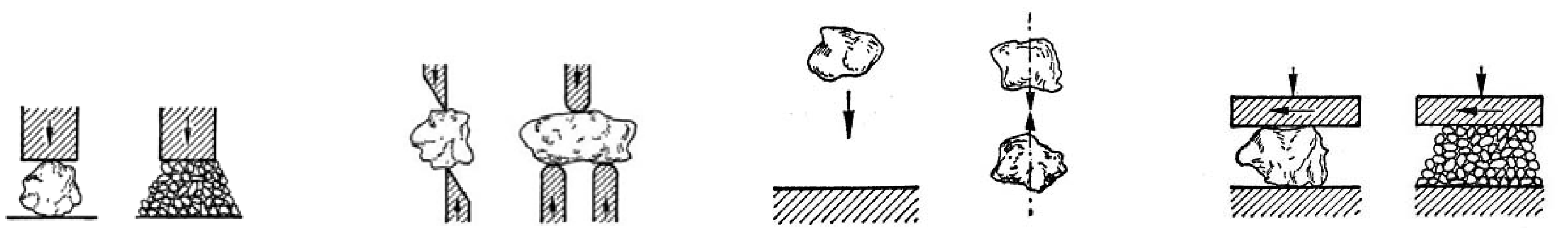
Content

- Background and objectives
- A new approach to optimize blade geometry of a mechanical mill using a computer simulation
- Effects of types of mill on powder properties
- How to control powder properties including pasting property, color and flavor by fine grinding

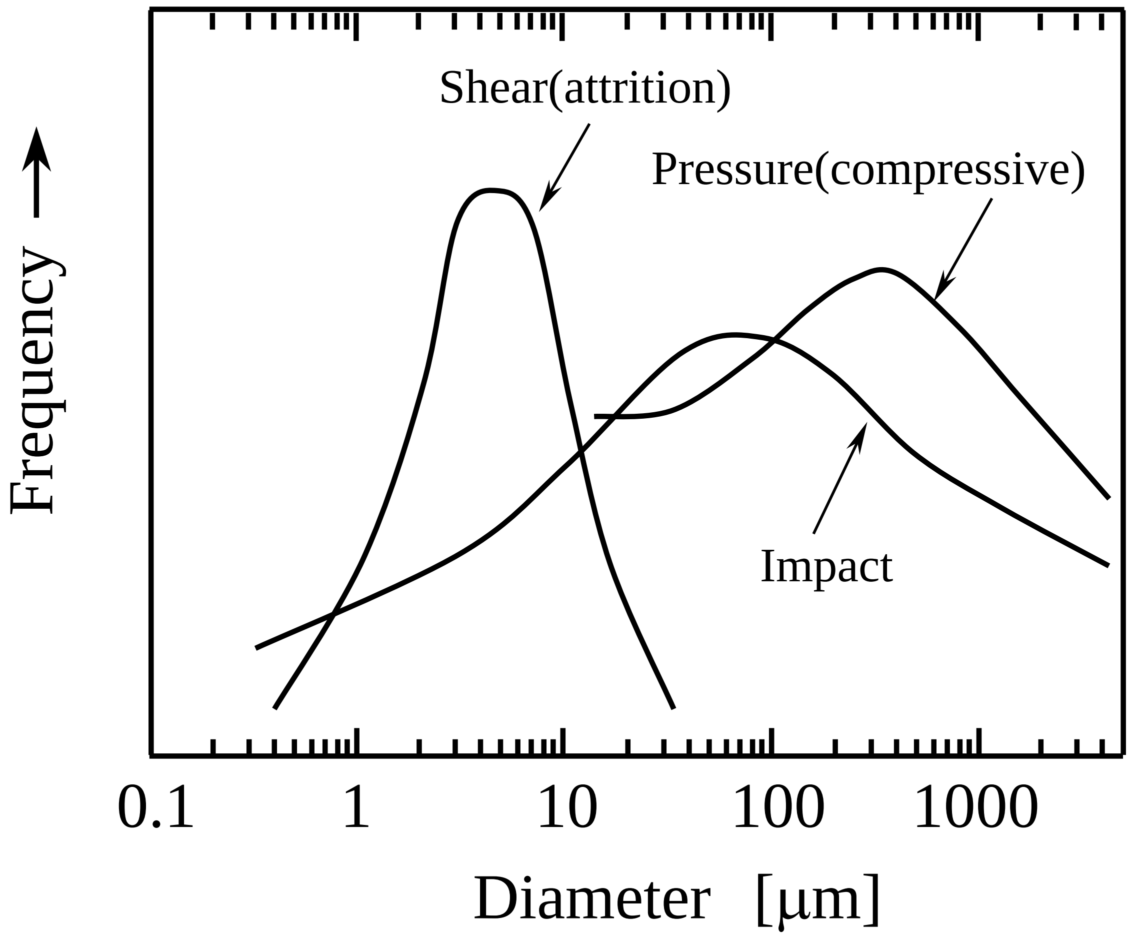
Background

Stress mechanisms in particle size reduction

a) Pressure between two surfaces (compressive)
b) Cutting between two surfaces
c) Shear stress
d) Impact with a solid surface
e) Impact with another particle
f) Attrition (friction)



(a) Pressure (b) Cutting & shear (c) Impact (d) Attrition



Typical particle distributions of powder ground by three kind of forces

Background

Stress mechanisms in particle size reduction

a) Pressure between two surfaces
b) Cutting between two surfaces
c) Shear stress
d) Impact with a solid surface
e) Impact with another particle
f) Attrition (friction)

Changes in powder properties:
particle size (surface area),
crystal structure etc.

Product quality
for food materials:
dissolution, absorption,
stability etc.

Objectives

1 Development of a new approach to optimize blade geometry of a mechanical impact mill for control of powder properties.

2 Control of powder properties for food materials by fine grinding

A new approach to optimize blade geometry of a mechanical impact mill

Numerical simulation:

Particle trajectories in a mechanical impact mill

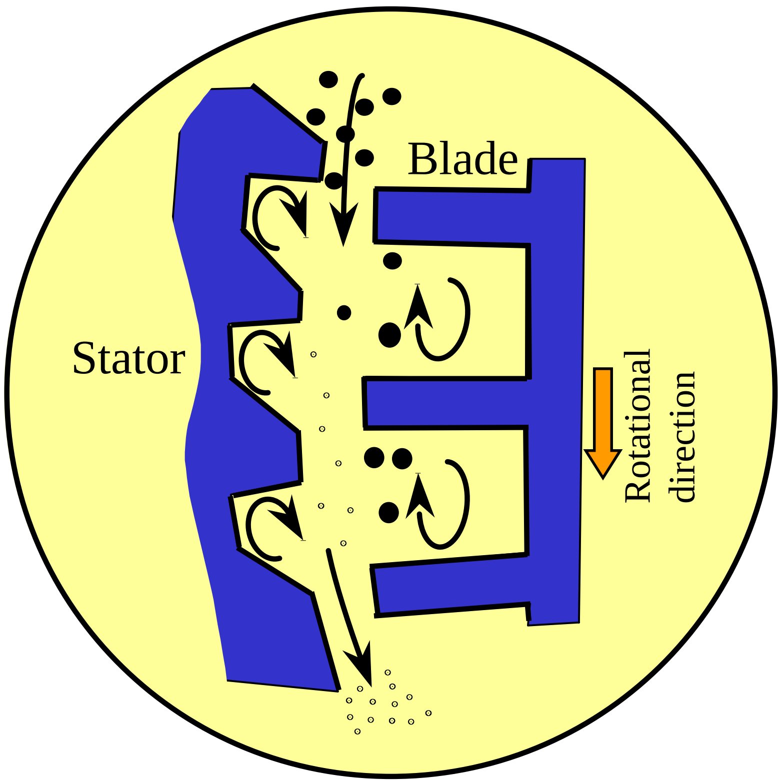
⇒ Impact energy

Experiment:

Calcium carbonate particles ground in a mechanical mill with various rotor blades

⇒ Particle size distribution, crystallinity changes

Grinding mechanisms of a mechanical impact mill



Grinding zone

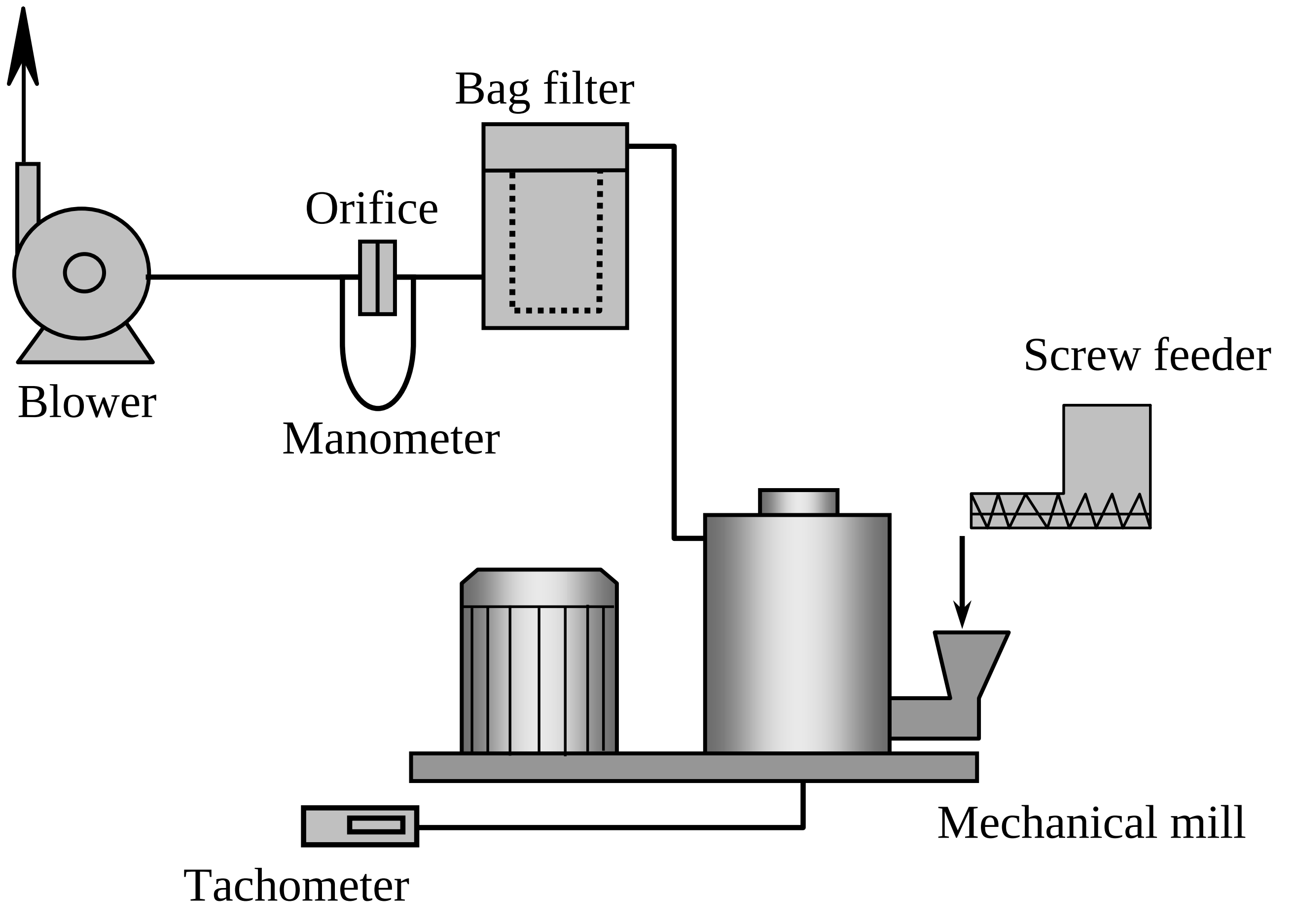
a) collision against walls (blades and stator)

b) collision with another particle

c) attrition on walls

d) cutting by blades

e) shear in a narrow gap between blade tip and stator



Experimental apparatus

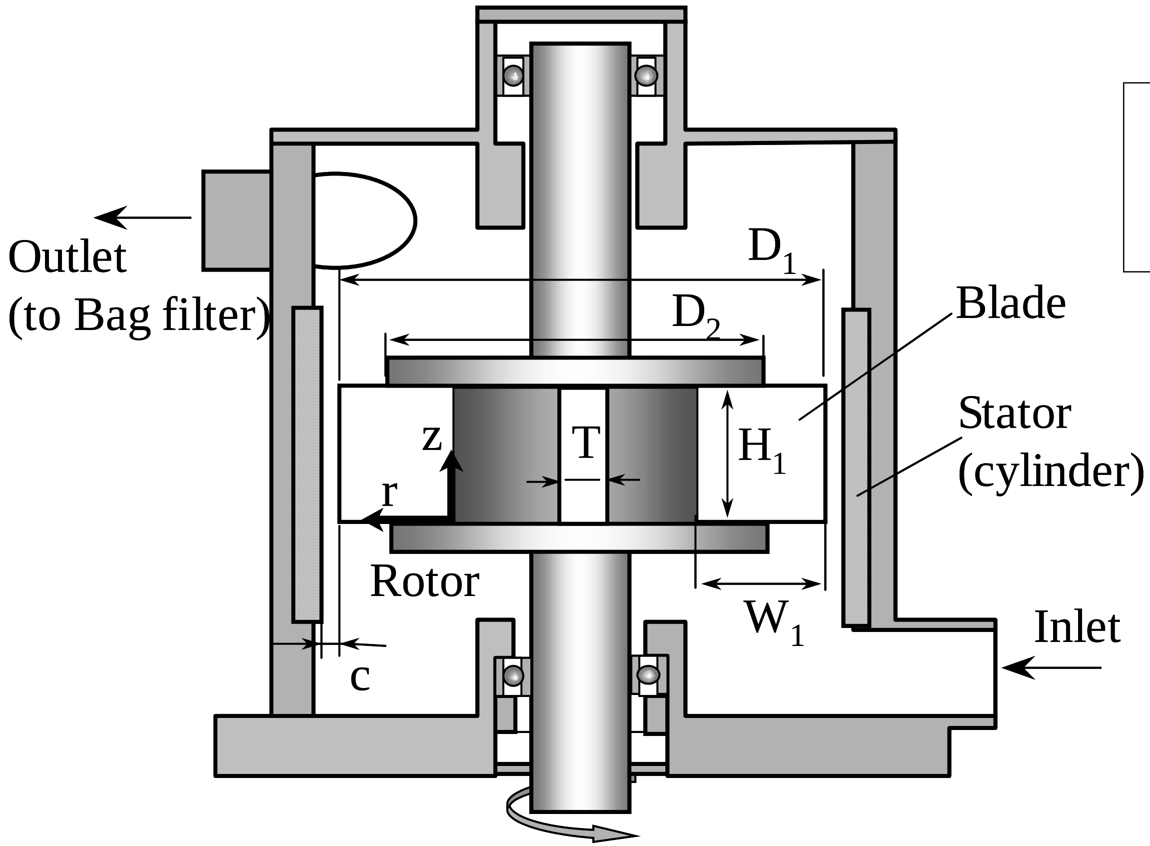
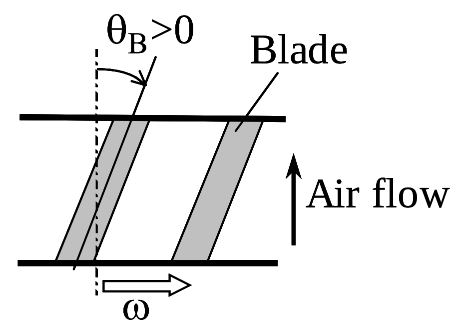


Table Dimensions

D_1=150mm,	D_2=136mm
W_1=20mm,	T=6mm
c=2mm,	H_1=40mm



Definition of blade angle

Cross-sectional diagram of a mechanical impact mill

Numerical simulations using Fluent

Flow field

Realizable k-ε turbulent model

Conditions:

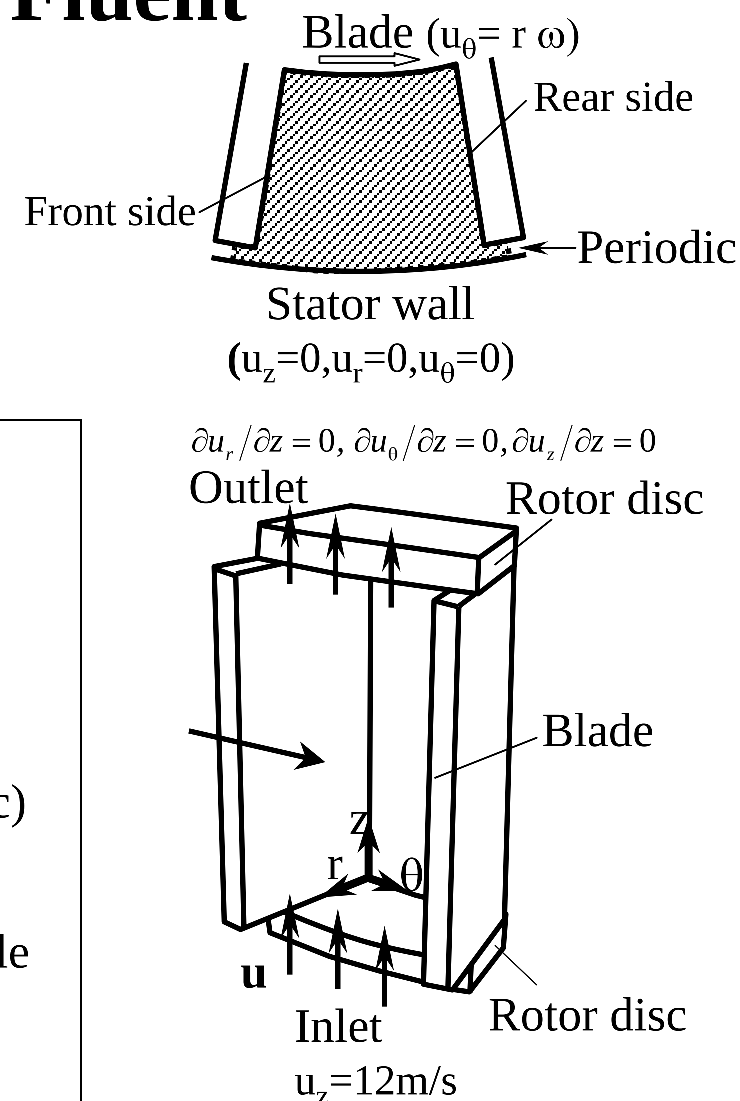
- Rotation speed ω: 14,000 min^{-1}
- Inlet velocity u_z: 12 m/s

Particles Trajectories

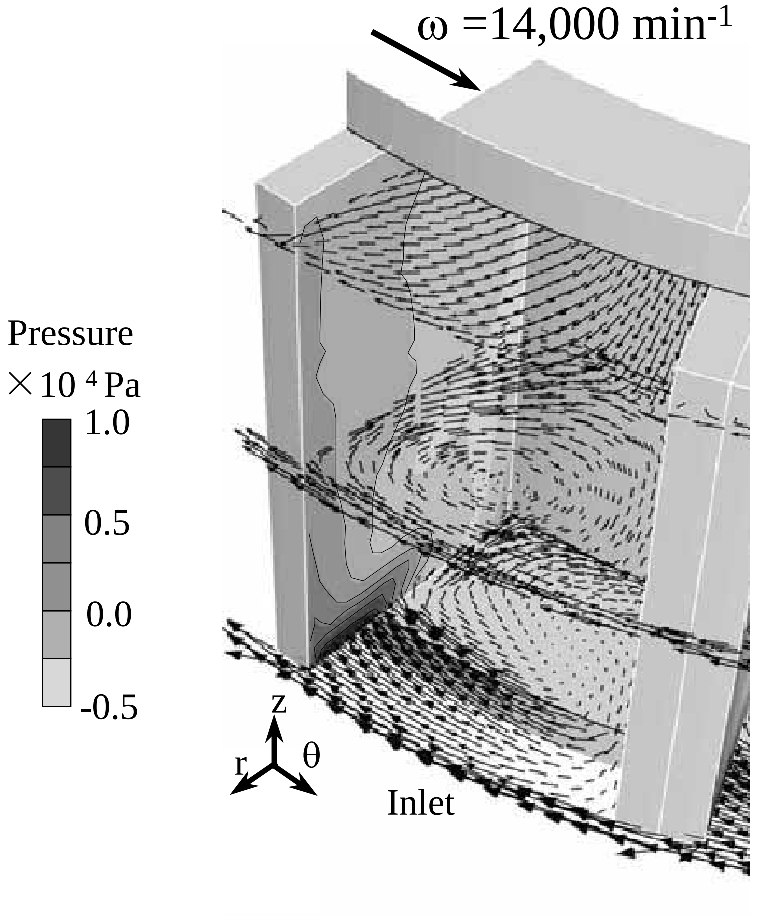
Lagrangian dispersed phase model

Conditions and assumptions:

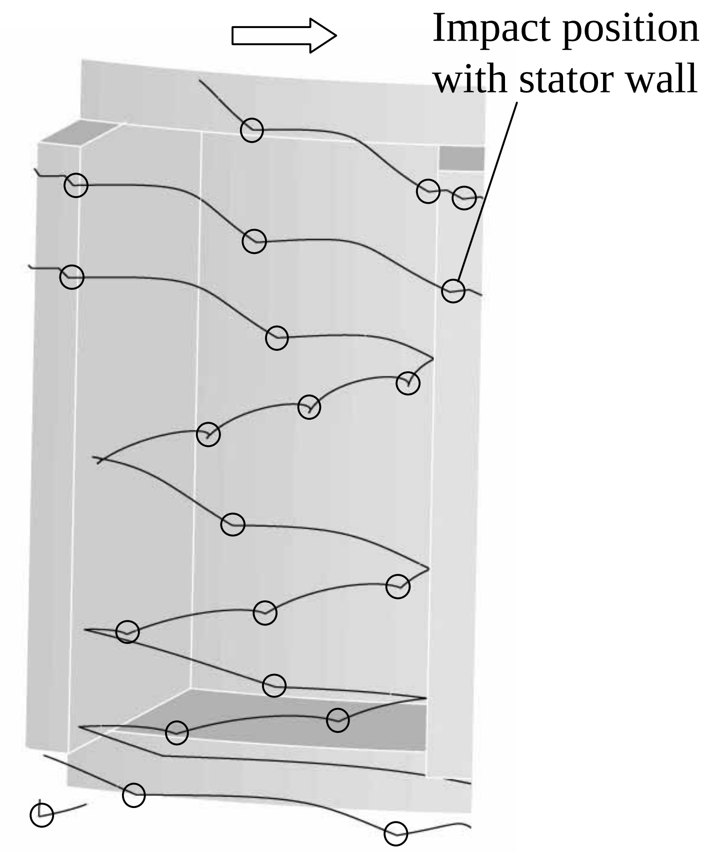
- Particle diameter D_p: 100 μm
- Particle density ρ_p: 1,400 kg/m^3
- Coefficient of restitution: 1 (perfectly elastic)
- Particle-particle interaction : negligible
- Effect of particles on air properties: negligible
- Change in particle size: negligible
- Number of particles: 100 (mono-sized)
- Injected velocity v: 0 m/s



Calculation region

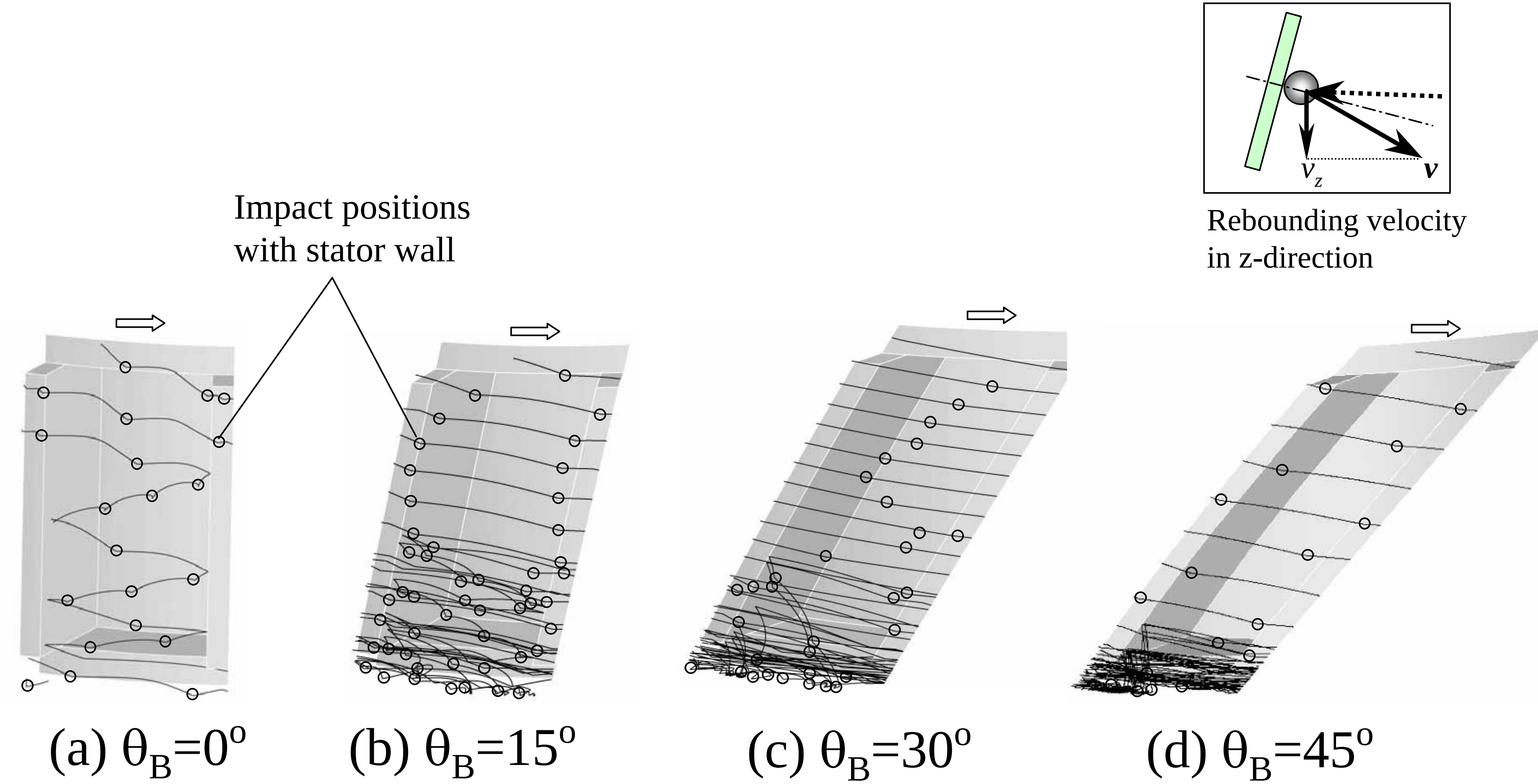


(a) Velocity vectors and pressure contours

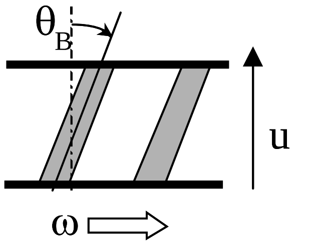


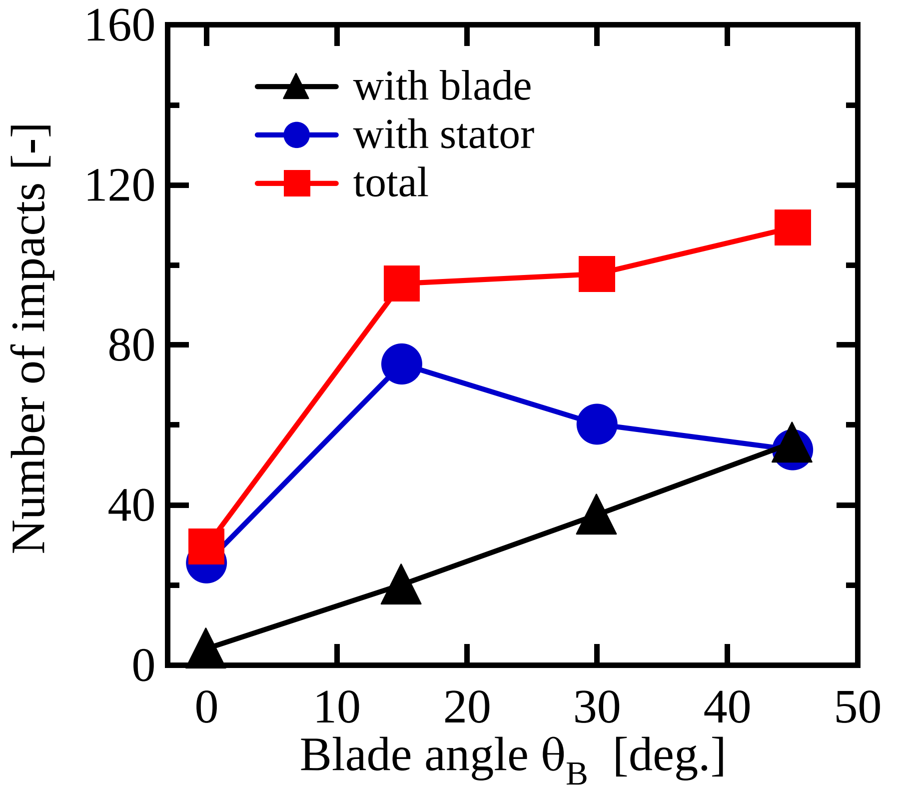
(b) Typical particle trajectories (D_p=100μm)

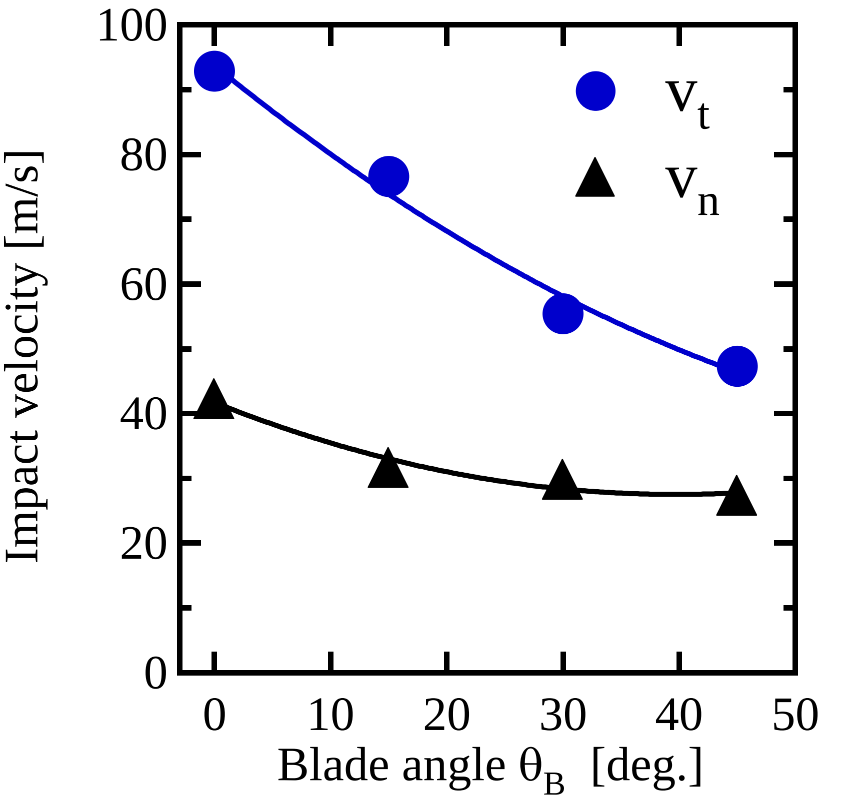
Calculated results for blade angle $\theta_B=0°$



Typical trajectories of a particle with a diameter of 100μm for various blade angles

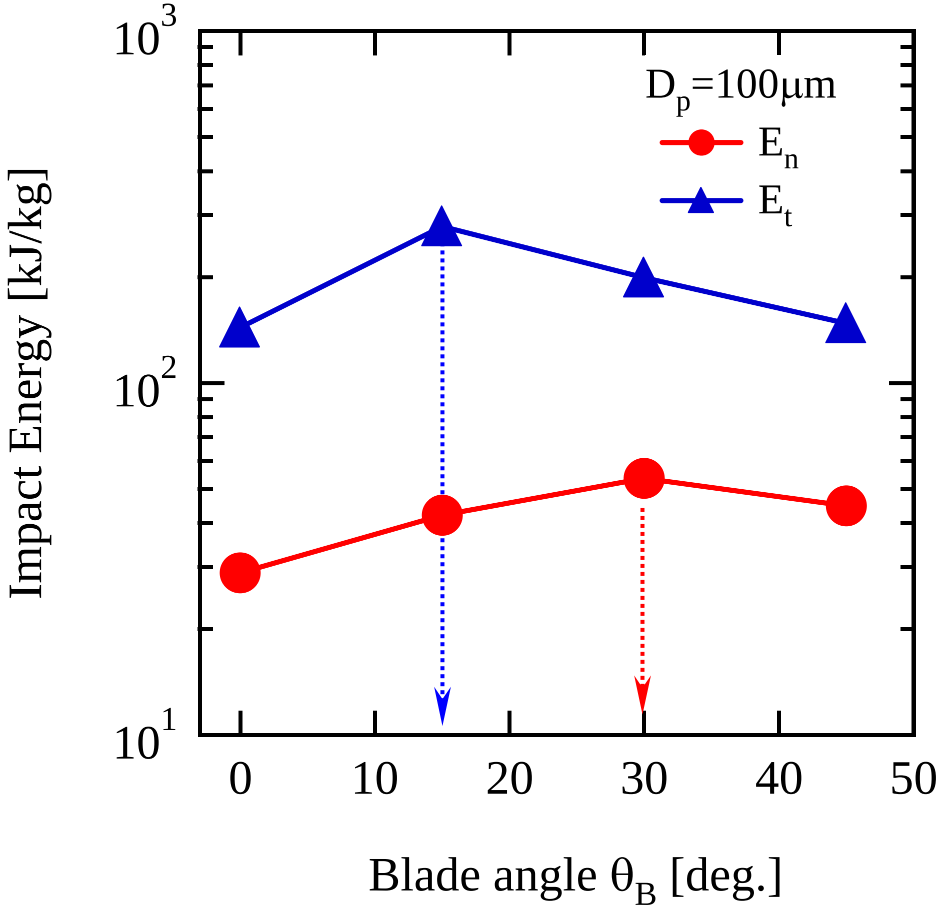






Number of impacts and impact velocity as a function of blade angle

NISSHIN ENGINEERING



The definition of impact energies per particle mass

$$E_n = \frac{1}{N_t}\sum_{i=1}^{N_t}\sum_{j=1}^{n_i}\left(\frac{1}{2}v_{n\ i,j}^{2}\right) \qquad (2)$$

$$E_t = \frac{1}{N_t}\sum_{i=1}^{N_t}\sum_{j=1}^{n_i}\left(\frac{1}{2}v_{t\ i,j}^{2}\right) \qquad (3)$$

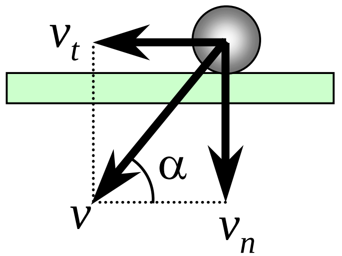
where

N_t=total number of injected particles[-]

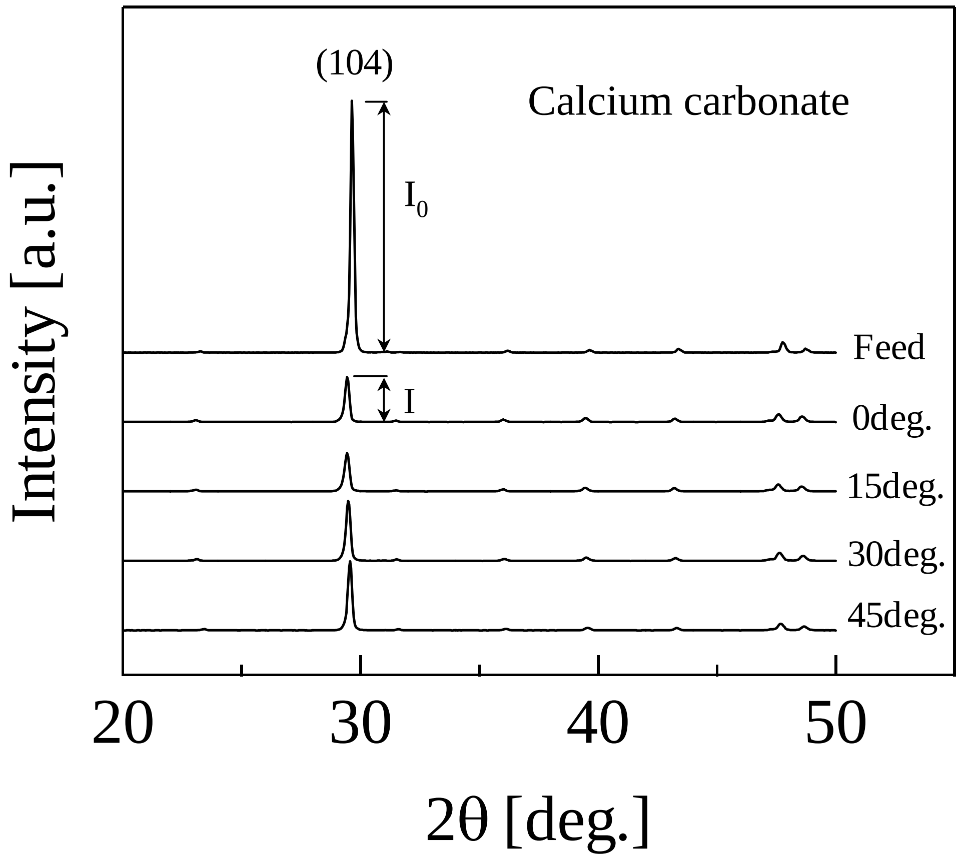
n_i=total number of impacts for an ith particle [-]

v_n=normal component of impact velocity [m/s]

v_t=tangential component of impact velocity [m/s]



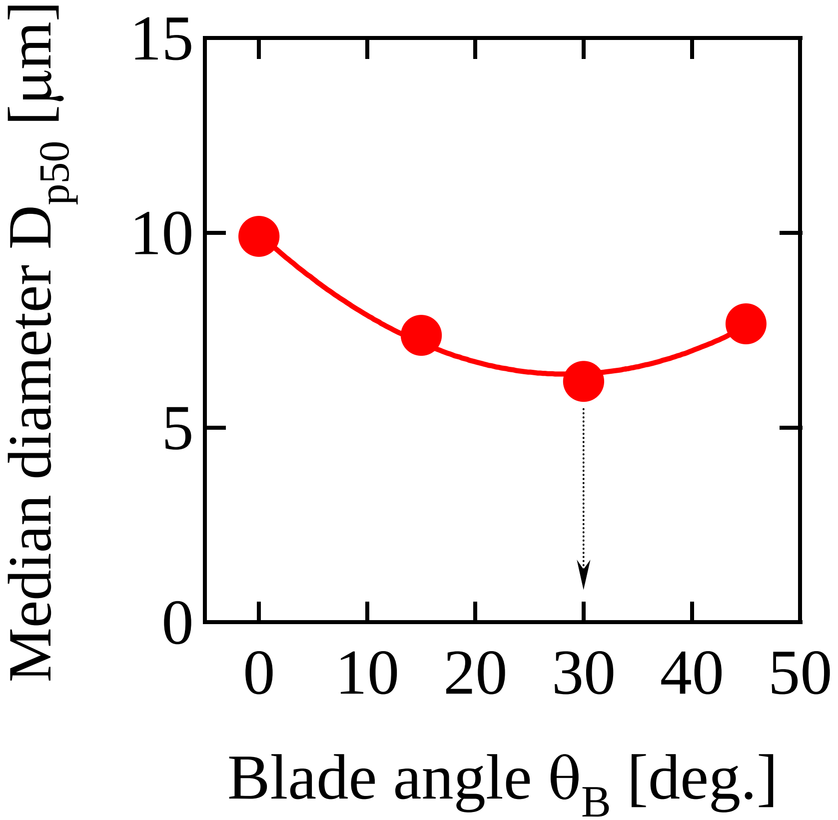
Normal impact energy E_n and tangential impact energy E_t by the computer simulation



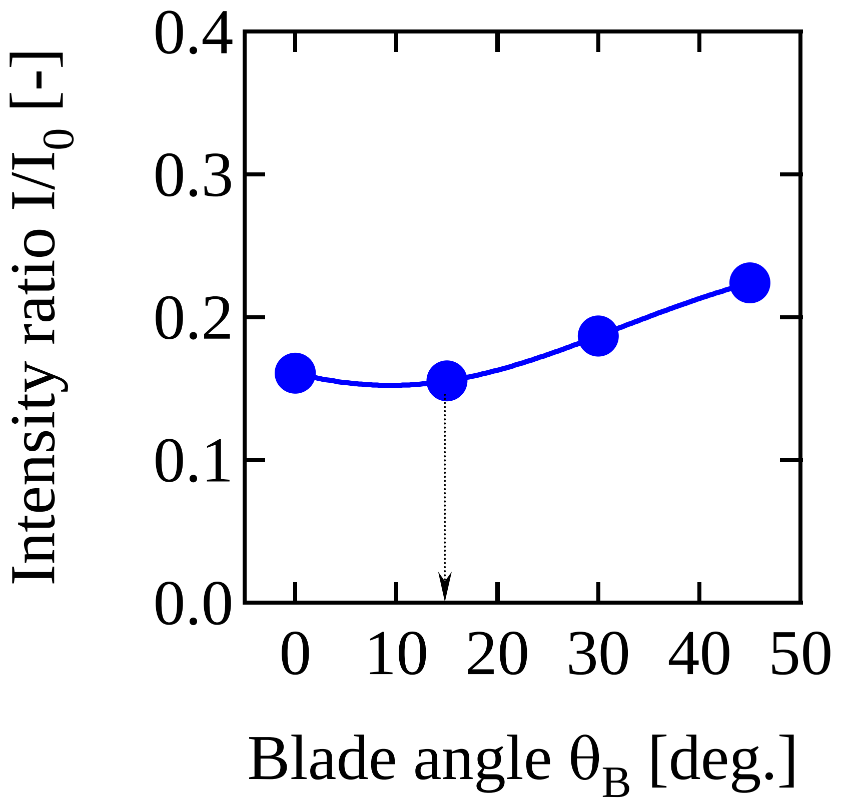
Estimation of change in crystallinity:

Intensity Ratio = I/I_0

X-ray diffraction (XRD) patterns for calcium carbonate particles ground in the impact mill with various blade angles



(a) Particle size



(b) Crystallinity

Changes in particle size and crystallinity of calcium carbonate particles ground in the impact mill with various blade angles

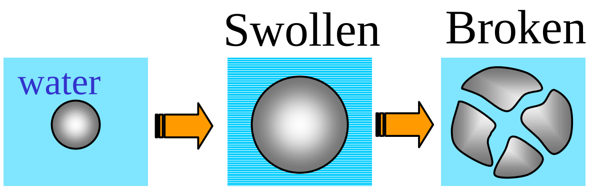
Another application of the optimizing approach -effects of blade angle on properties of potato starch particles-

Material: Potato starch

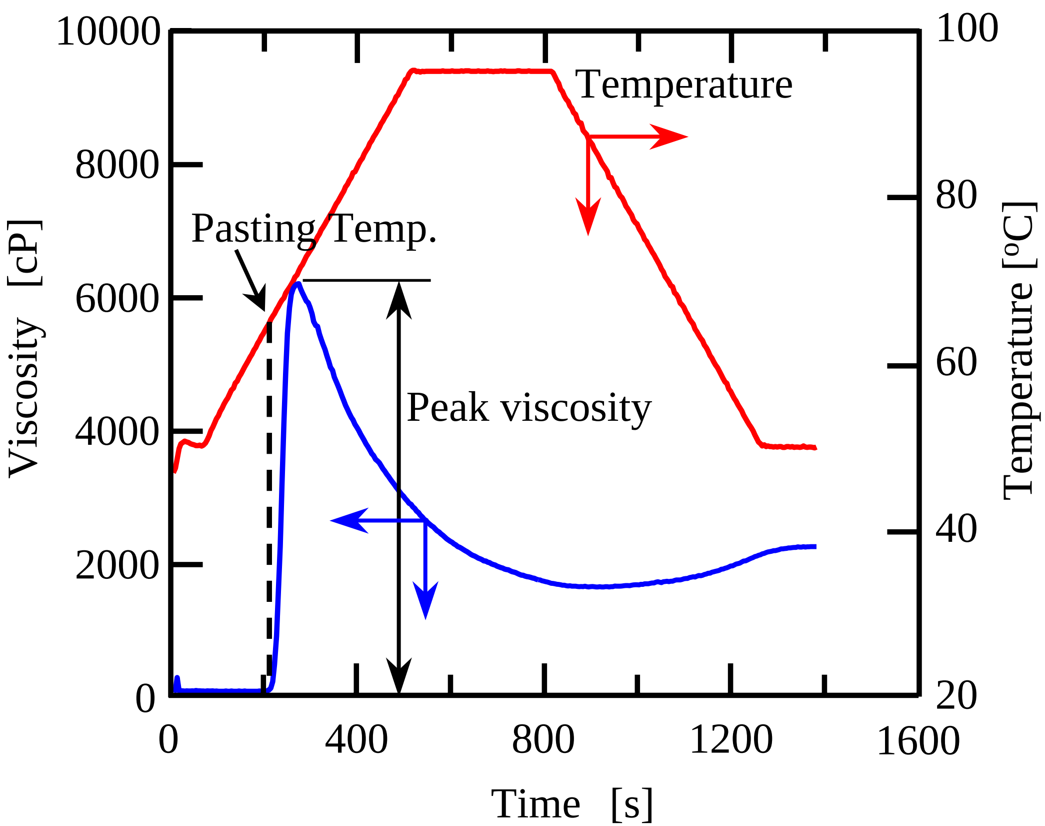
Mill: the mechanical impact mill
with different blade angles

Measurement
- Particle size
- Crystallinity
  - X-ray diffraction (XRD)
- Pasting properties:
  - Rapid Visco Analyser (RVA)

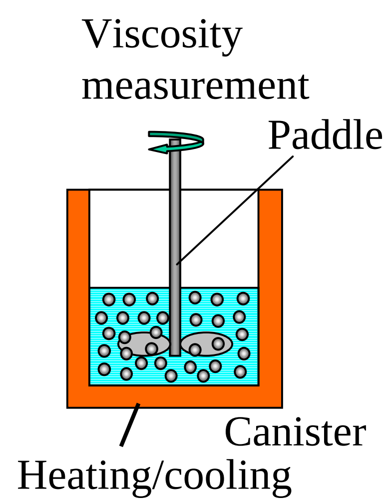
RVA (Rapid Visco Analyser, Newport Scientific Pty. Ltd.)



Pasting state in the RVA

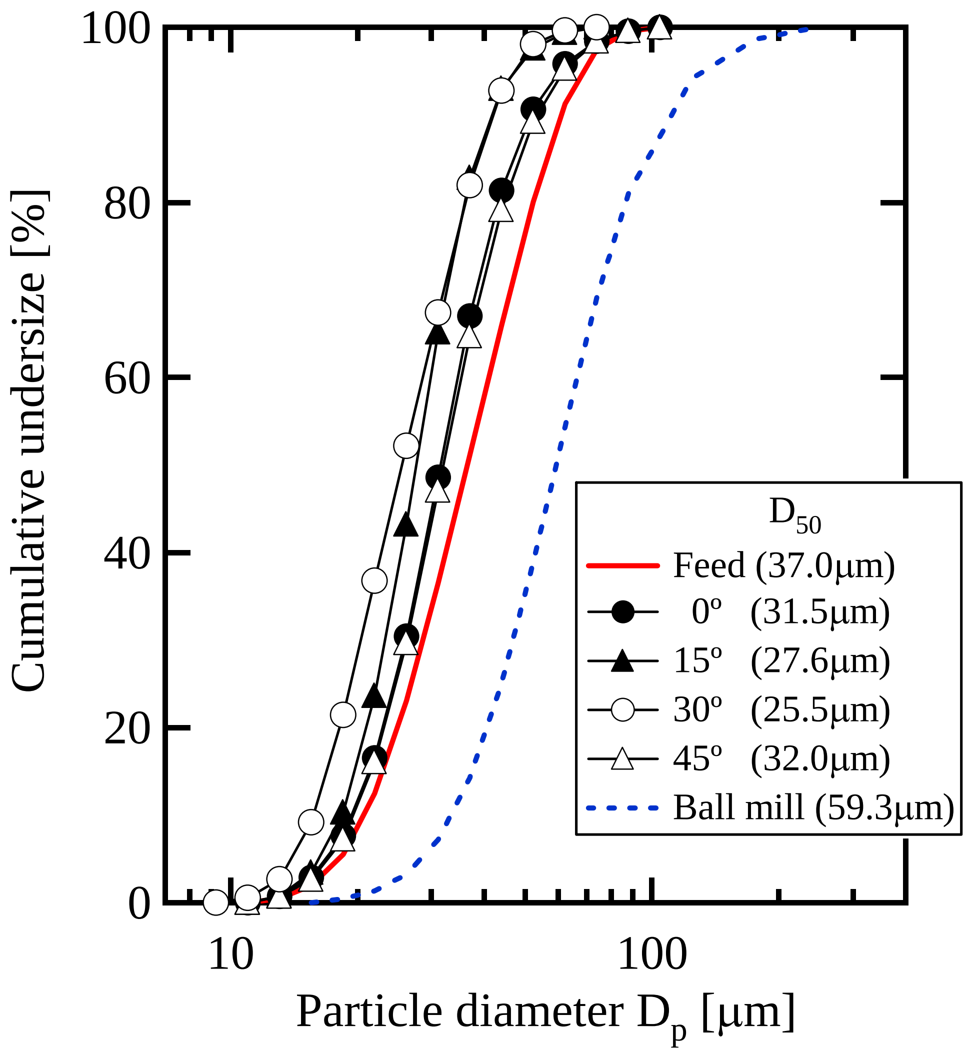


Typical RVA pasting curve

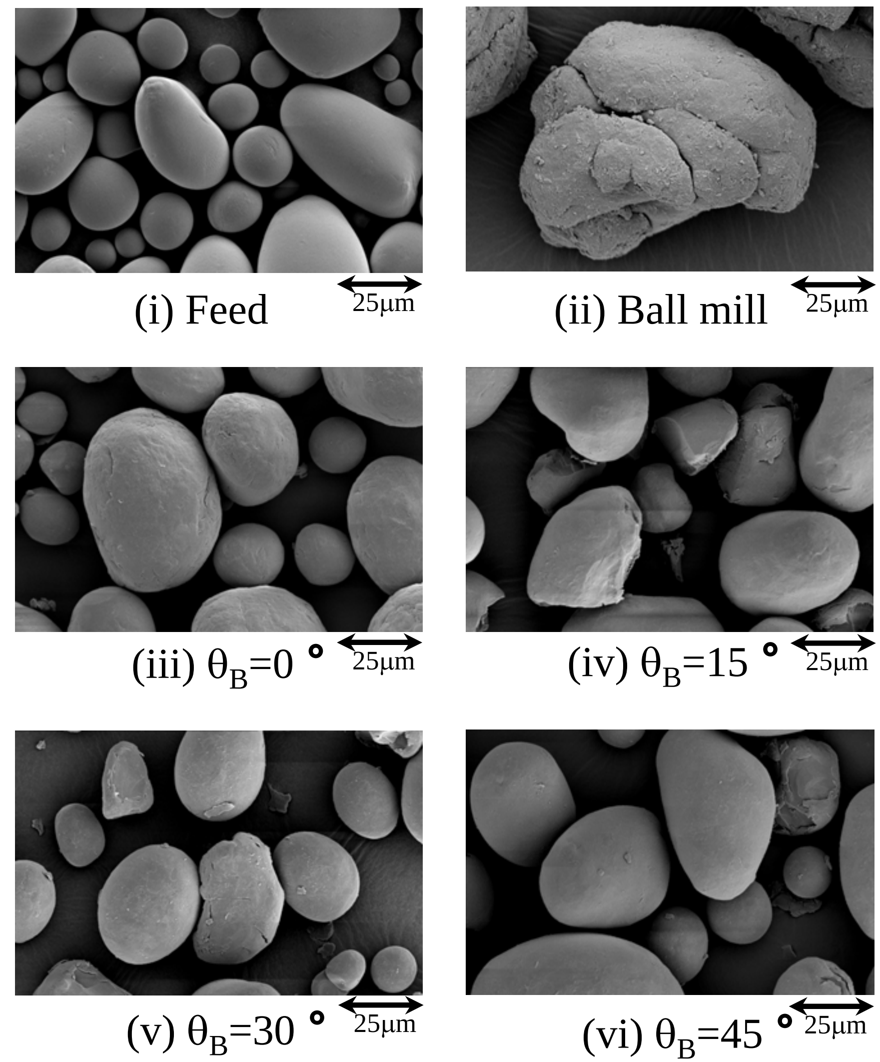


Parameters for pasting properties

- Pasting temperature:
  - Temperature where viscosity first increases
- Peak viscosity:
  - Maximum viscosity



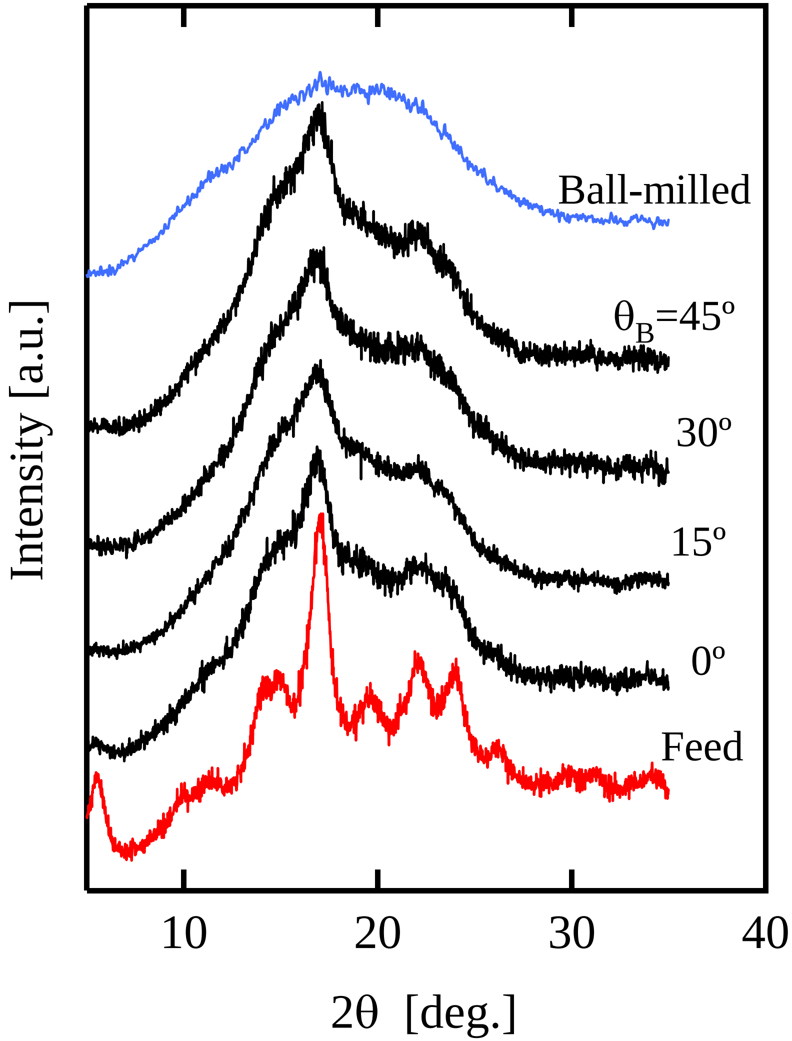
(a) Particle size distributions



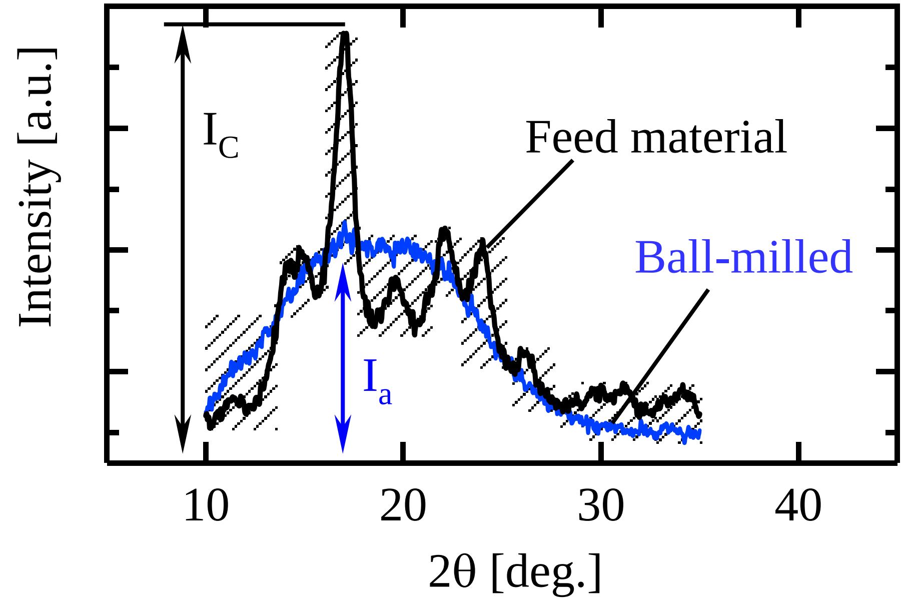
(b) SEM Photos

Potato starch particles ground in the impact mill with various blade angles and a ball mill

NISSHIN ENGINEERING



(a) X-ray diffraction patterns



Crystalline index (Wakelin *et al.*)

$$C = \frac{\int |I_s - I_a| d \cdot 2\theta}{\int |I_c - I_a| d \cdot 2\theta} \qquad (1)$$

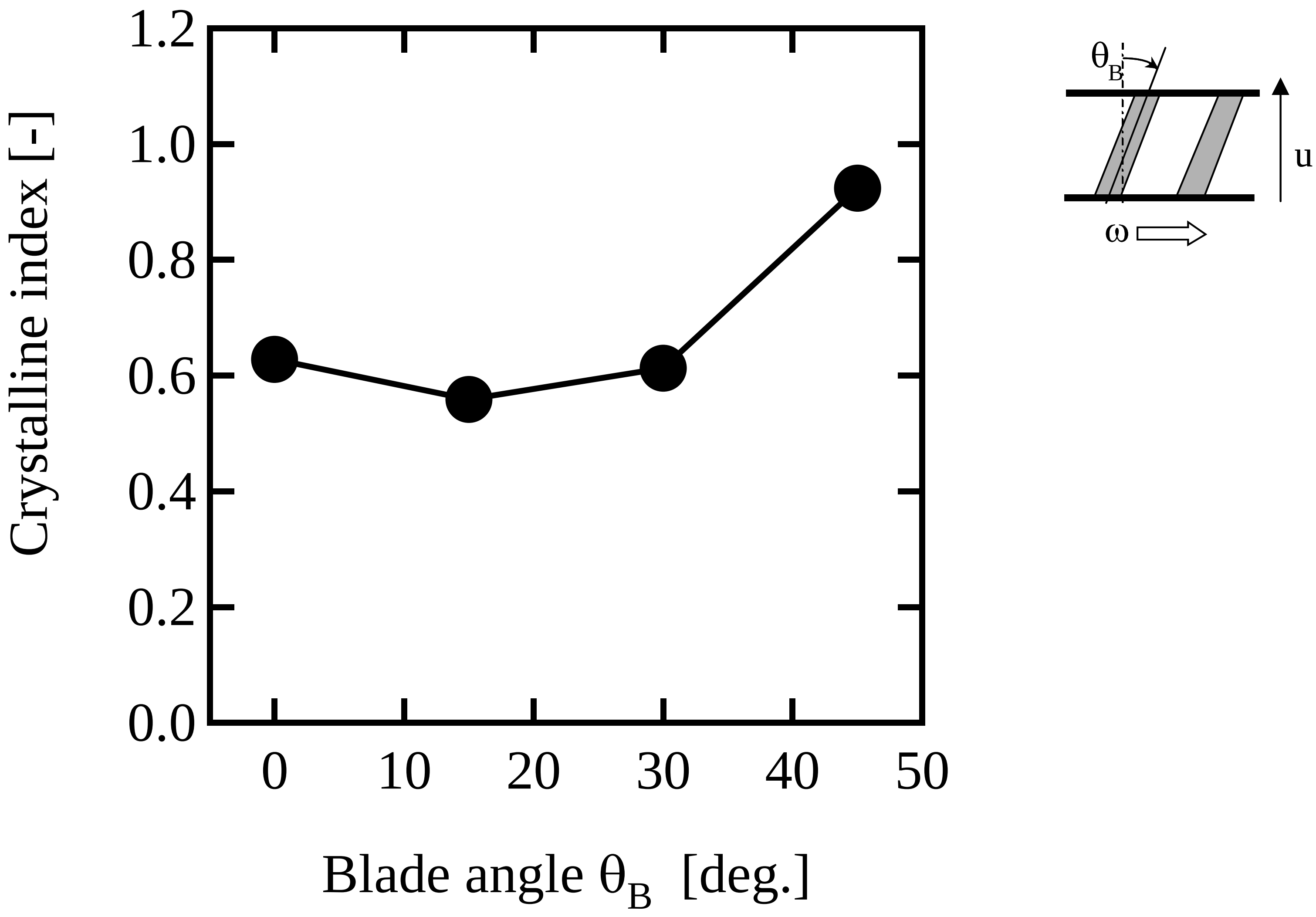
where

I_c: intensity of feed particles (crystalline)

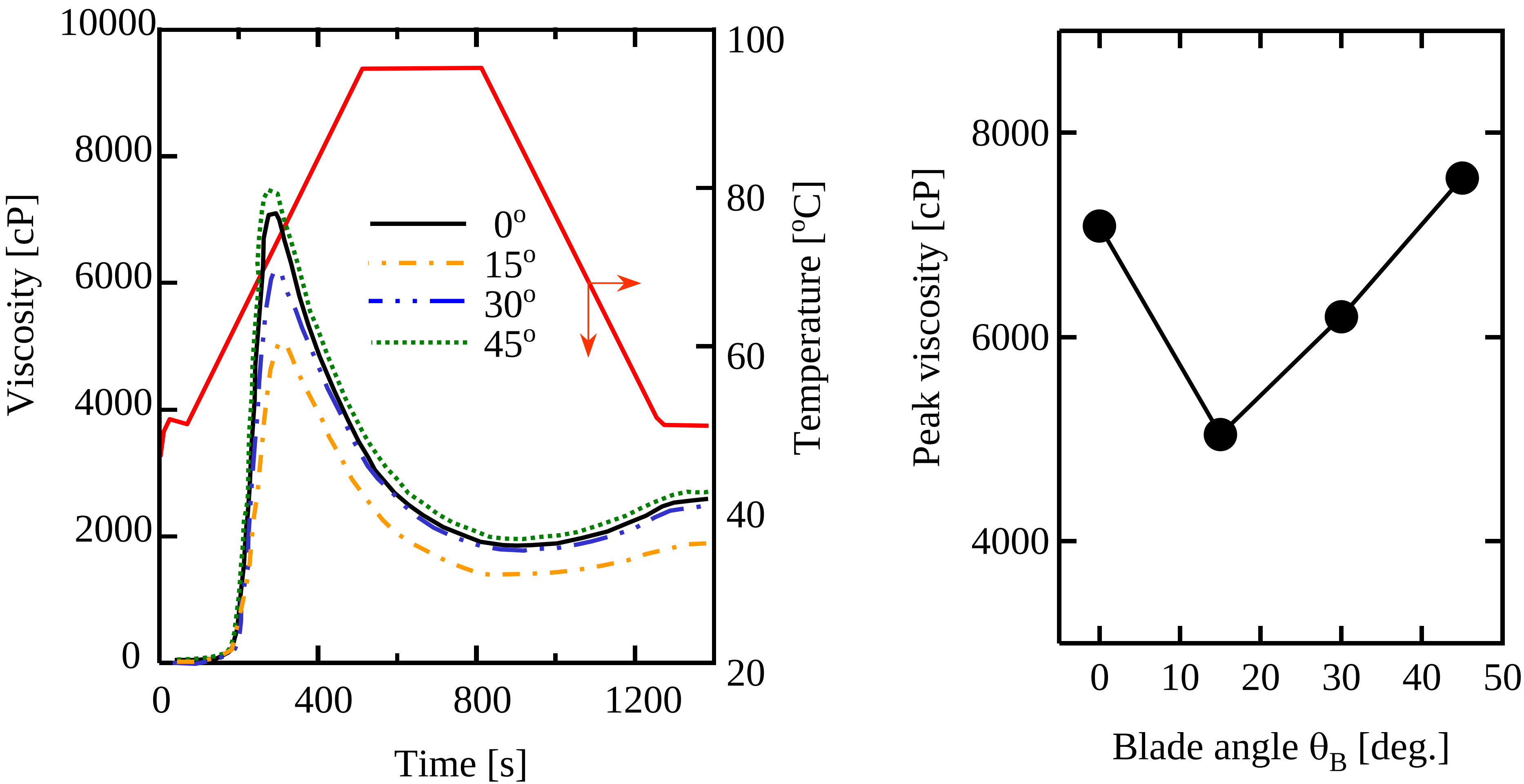
I_a: intensity of ball-milled particles (amorphous)

I_s: intensity of pulverized particles

X-ray diffraction (XRD) patterns and the definition of crystalline index for potato starch particles



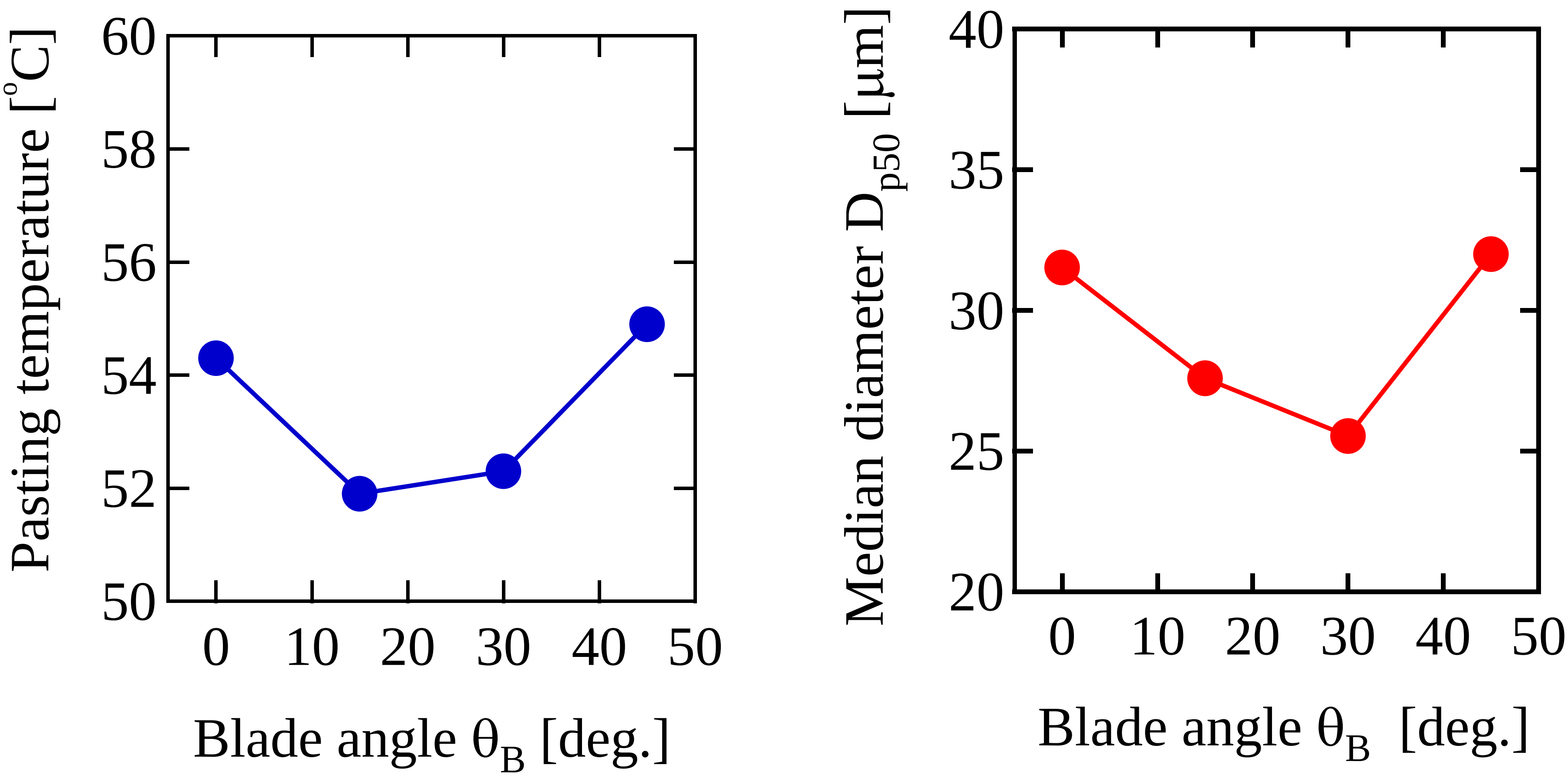
Changes in crystallinity for potato starch particles ground in the impact mill with various blade angles



(a) RVA pasting curve (b) Peak viscosity

Pasting properties of potato starch particles ground in the impact mill with various blade angles

NISSHIN ENGINEERING



(a) Pasting temperature

(b) Particle size

Changes in properties of potato starch particles ground in the impact mill with various blade angles

NISSHIN ENGINEERING

Effects of types of mill on powder properties

Material: Potato starch

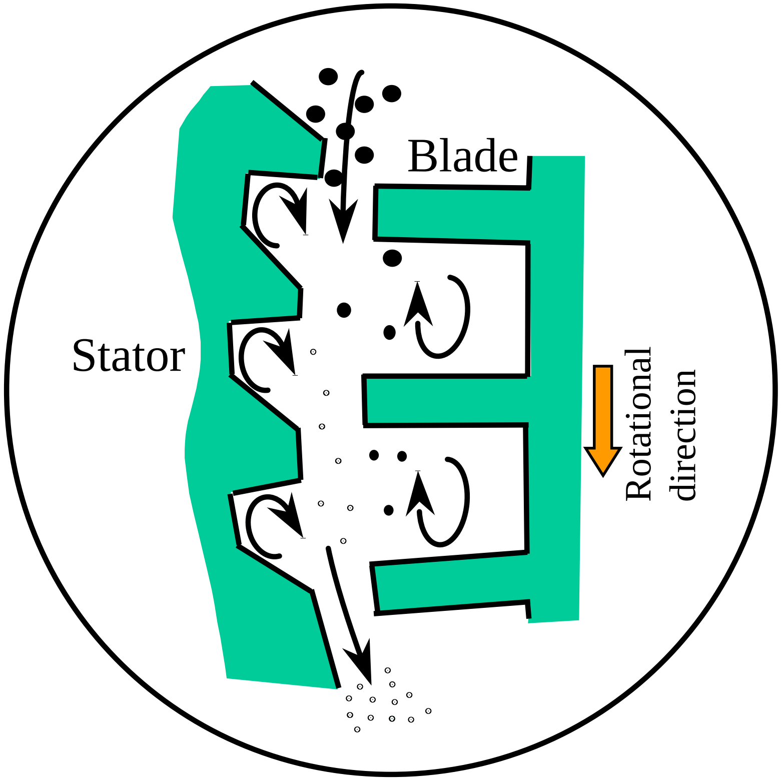
Mills: a mechanical impact mill, a jet mill, a ball mill

Measurement:
Particle size, crystallinity, pasting properties

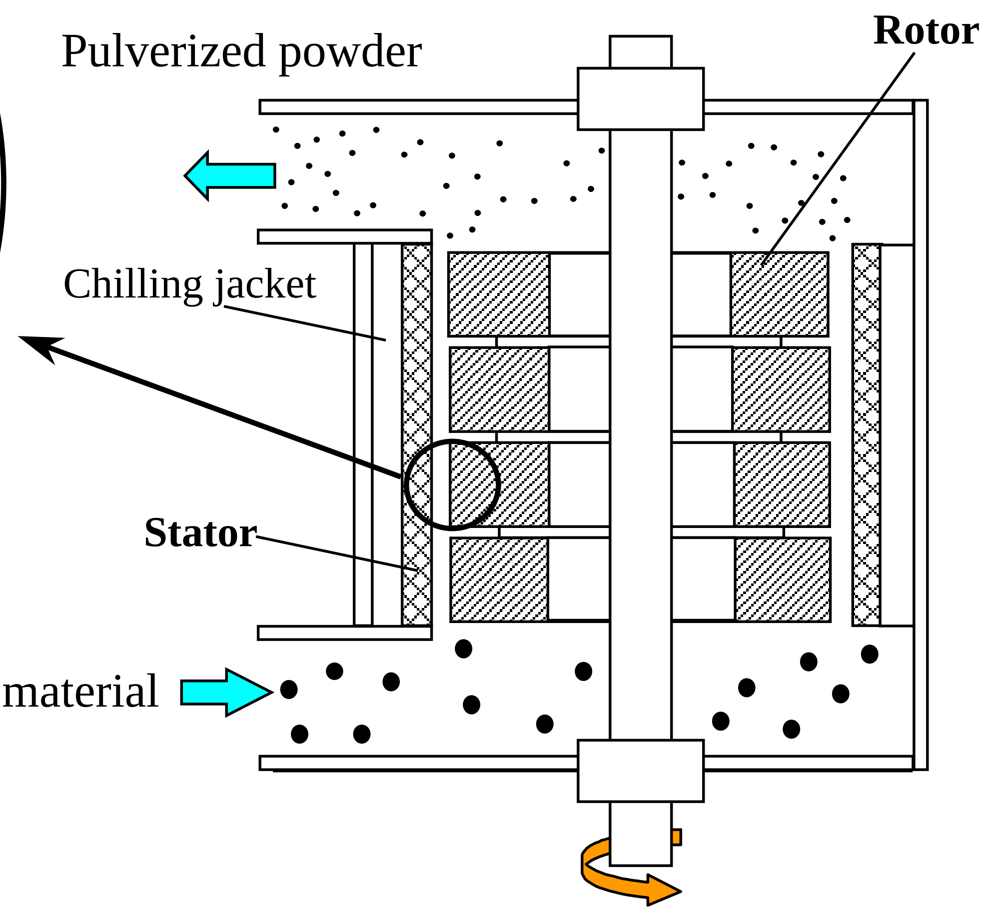
Mechanical mill:Blade Mill

Jet mill:Super Jet Mill

NISSHIN ENGINEERING

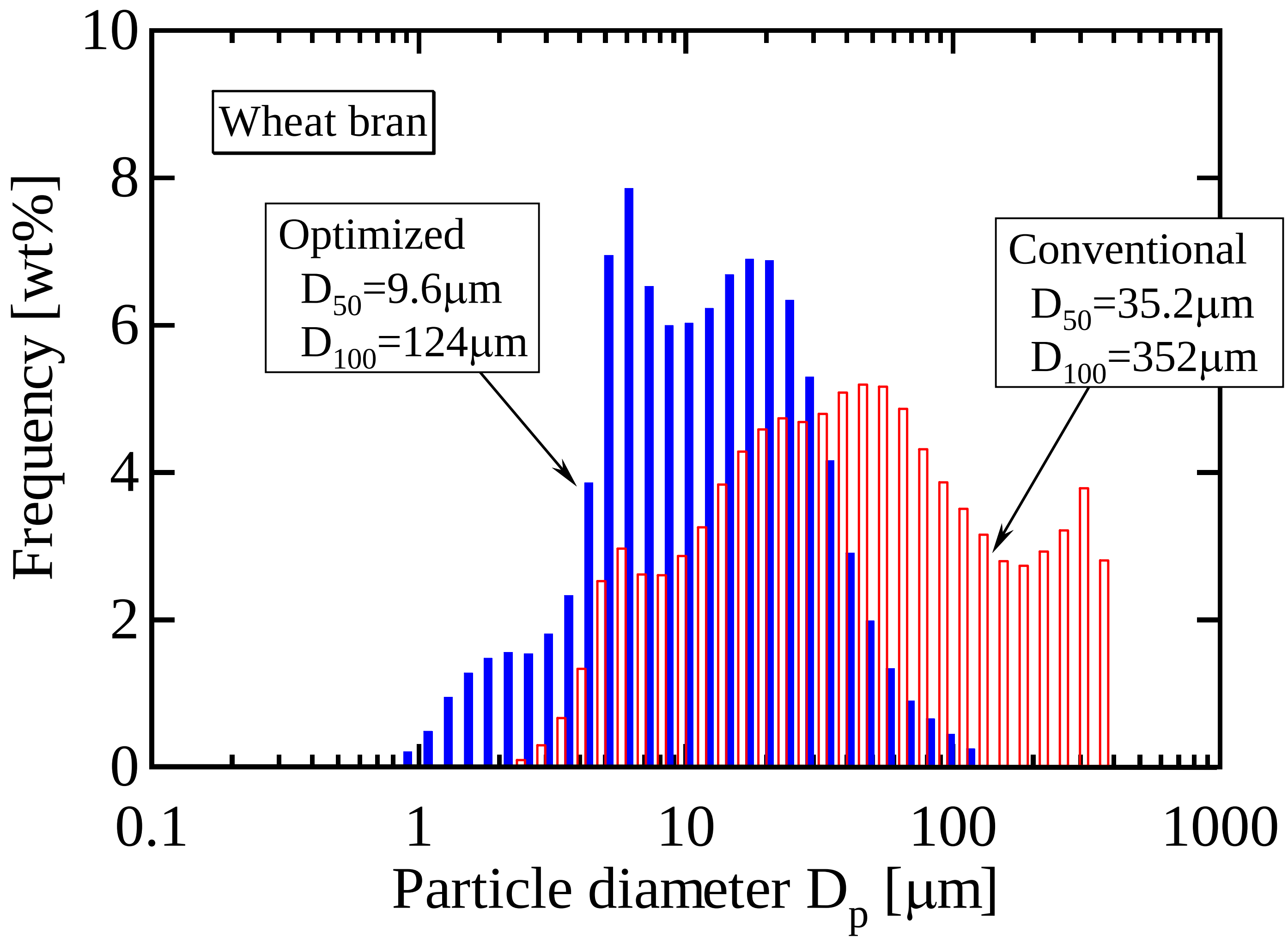


Pulverizing zone



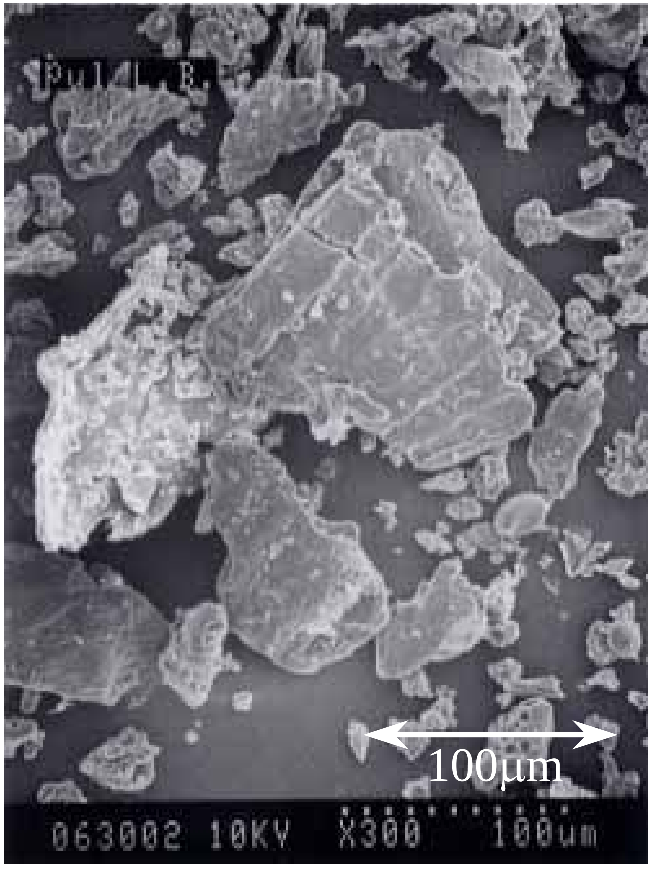
Structure of a mechanical impact mill (Blade Mill)

NISSHIN ENGINEERING



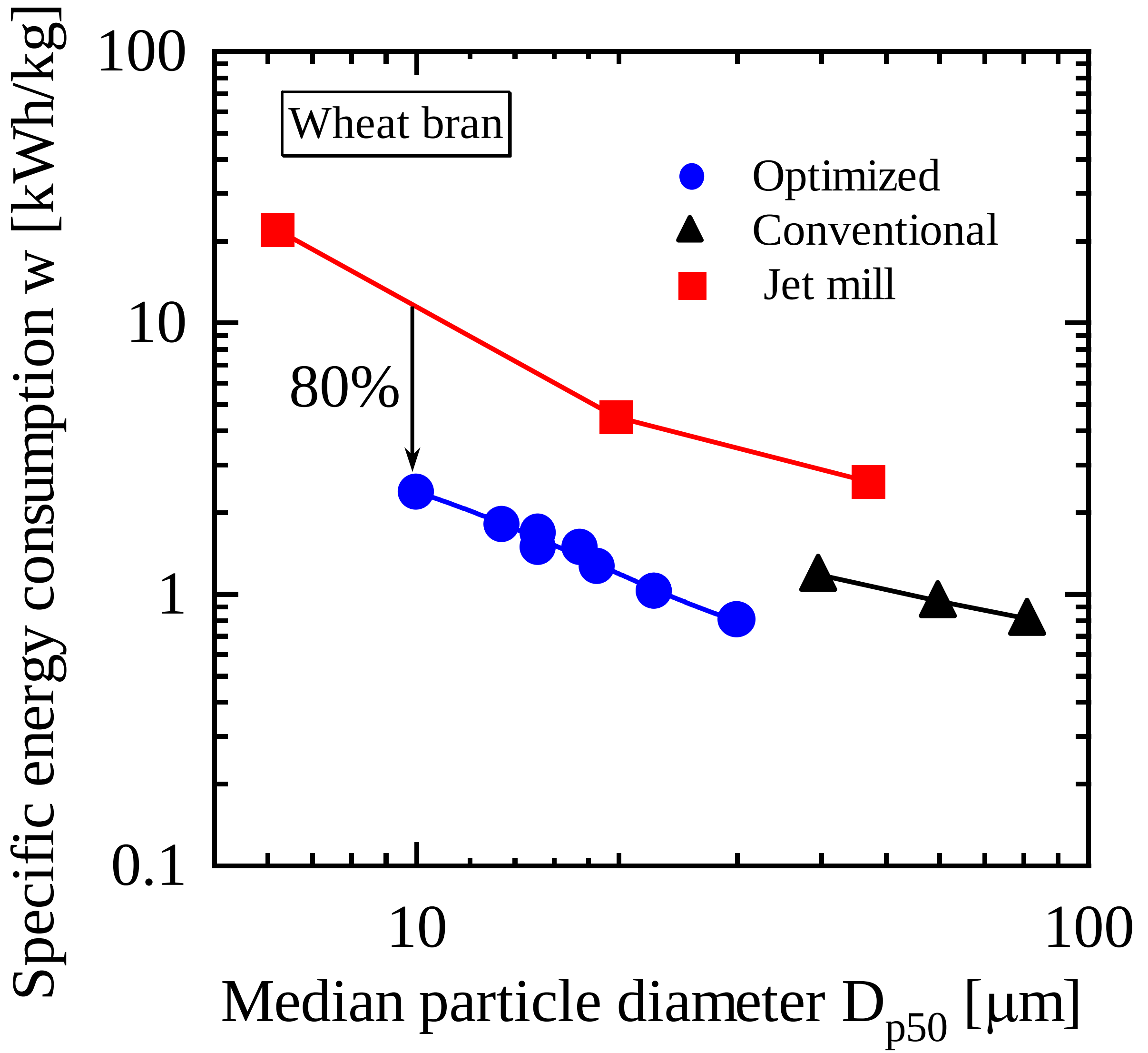
Comparison of particle size distributions for wheat bran ground in optimized and conventional mechanical mills

Optimized mill



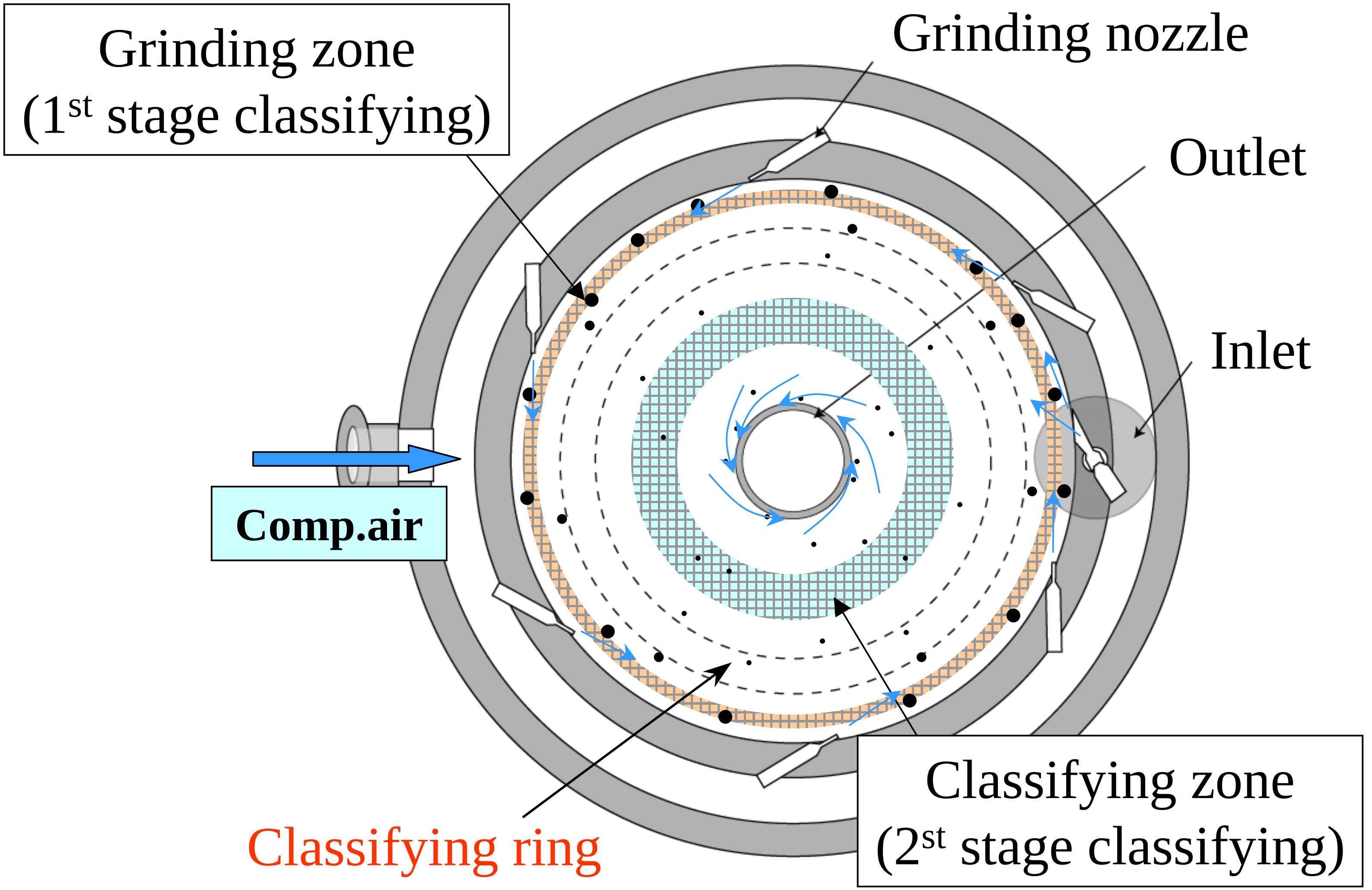
Conventional mill

SEM photos of wheat bran powder ground in optimized and conventional mechanical mills



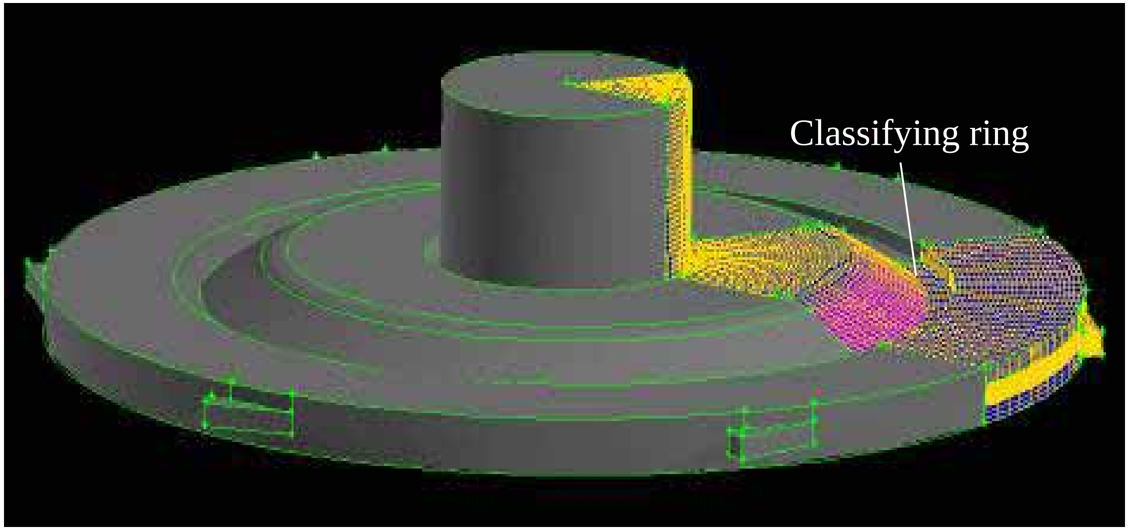
Comparison of specific energy consumption in the optimized mechanical mill, a conventional mechanical mill and a jet mill

NISSHIN ENGINEERING

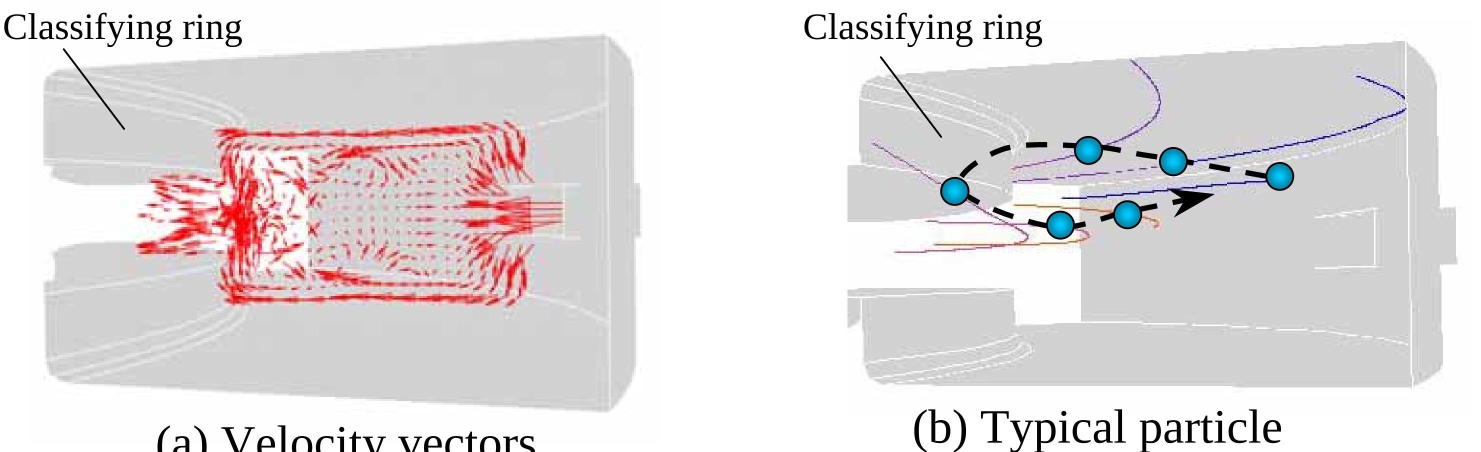


Structure of a jet mill (Super Jet Mill)

NISSHIN ENGINEERING



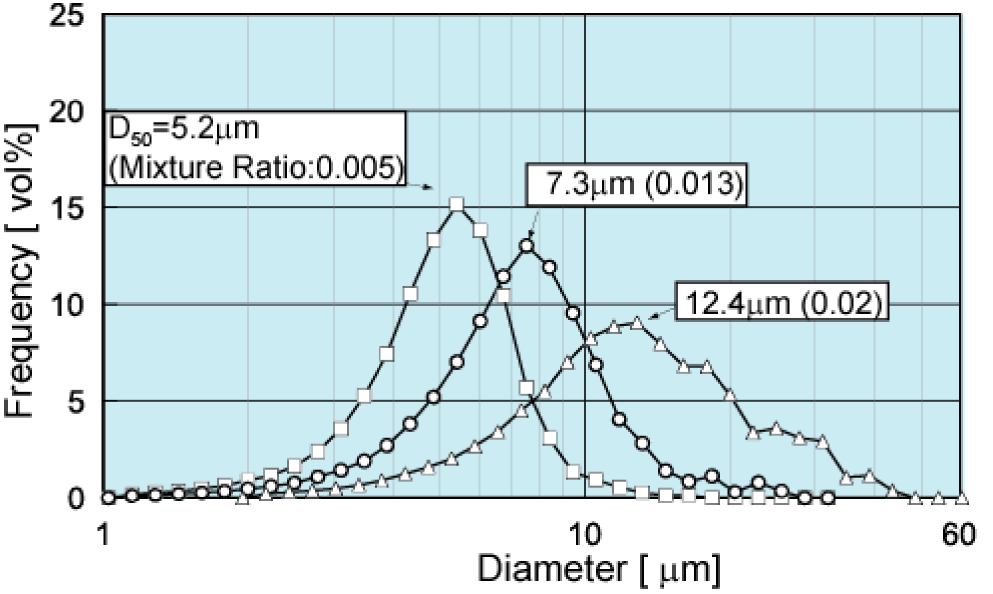
Inner wall structure (calculation region)



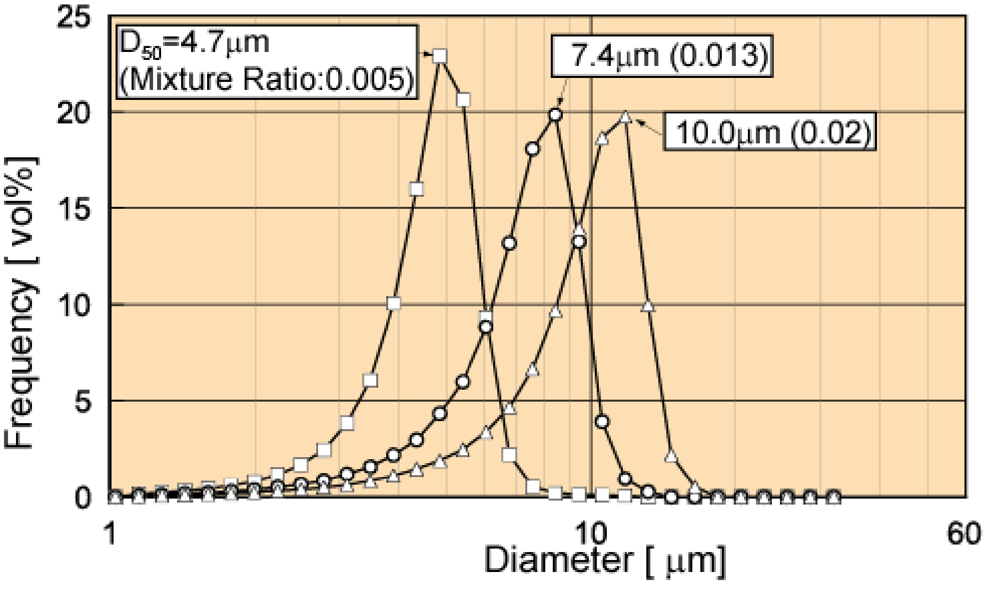
(a) Velocity vectors

(b) Typical particle trajectories (D_p=10μm)

Calculated results in the Super jet mill



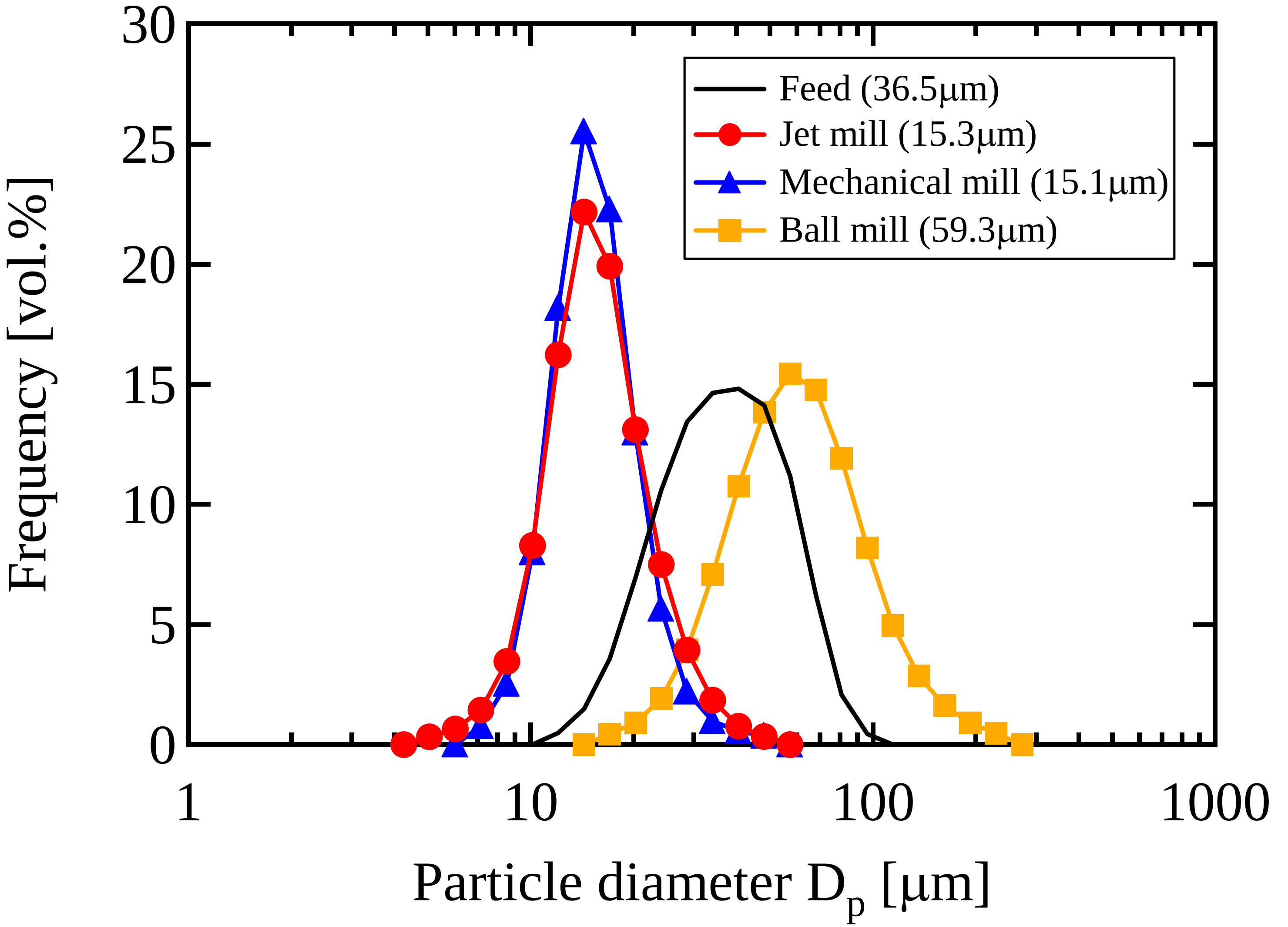
Conventional jet mill



Super Jet Mill

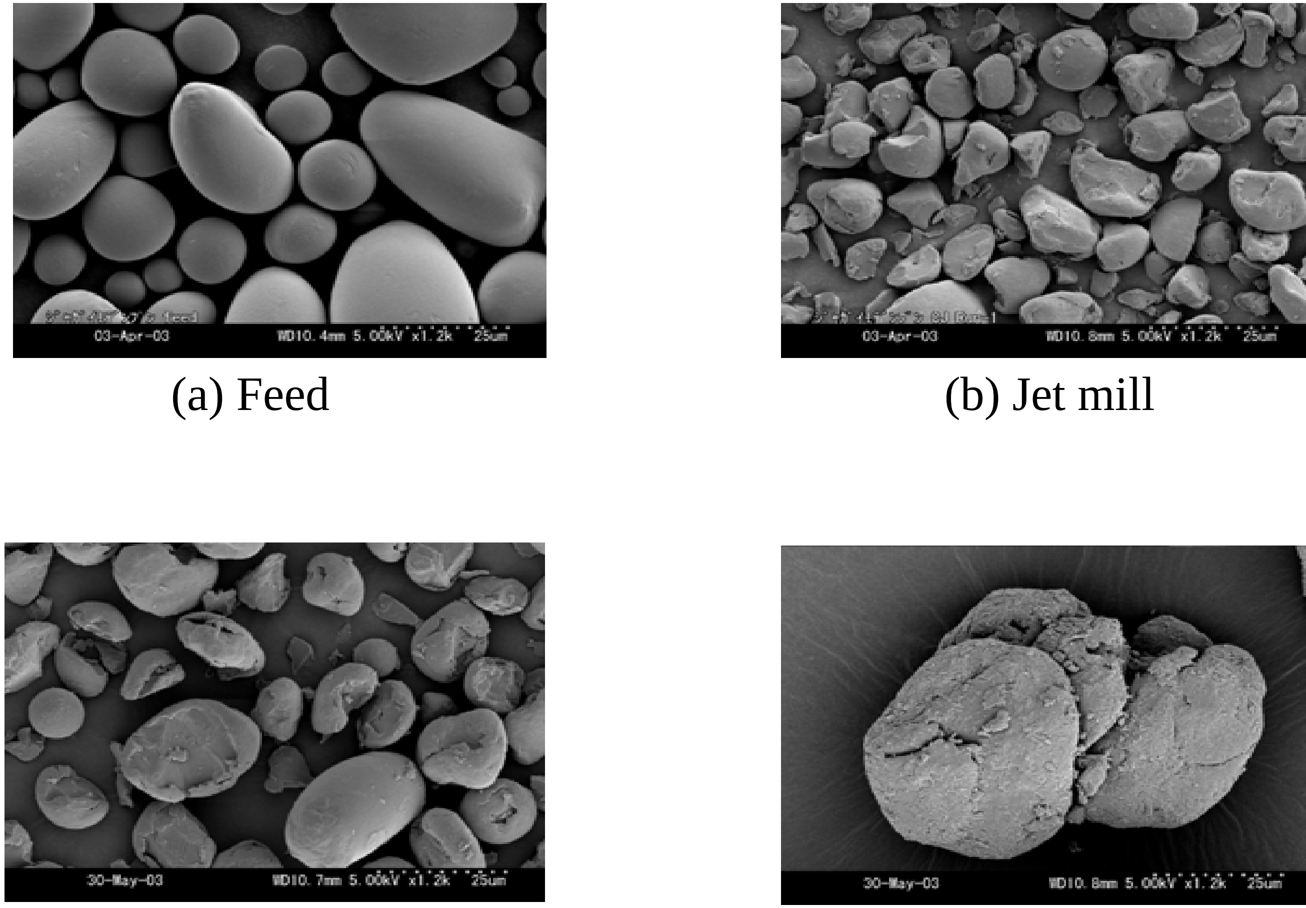
Relation between particle size distribution of product and mixture ratio (color toner)

NISSHIN ENGINEERING



Particle size distributions of potato starch particles ground in various mills

NISSHIN ENGINEERING



(a) Feed

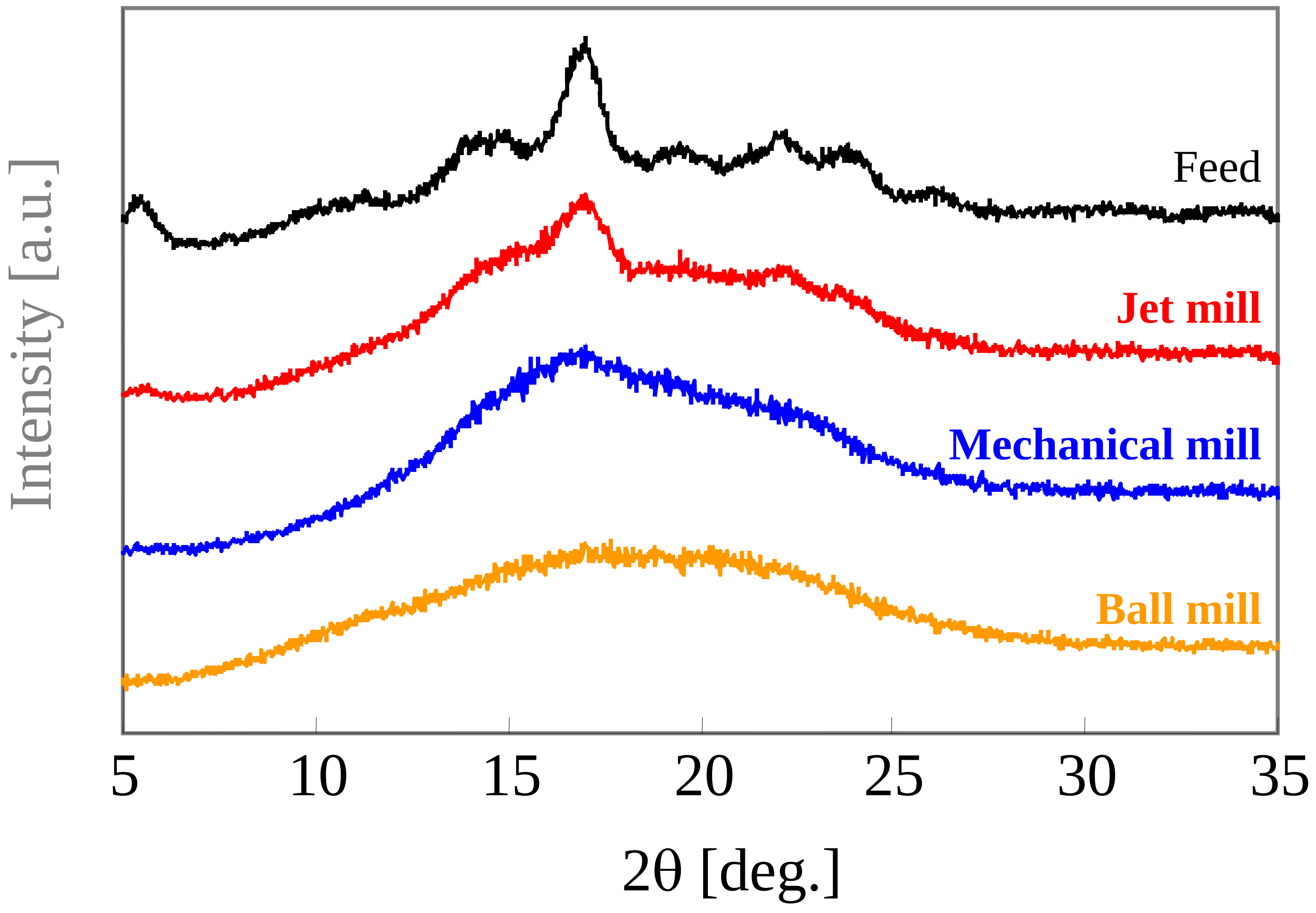
(b) Jet mill

(c) Mechanical mill

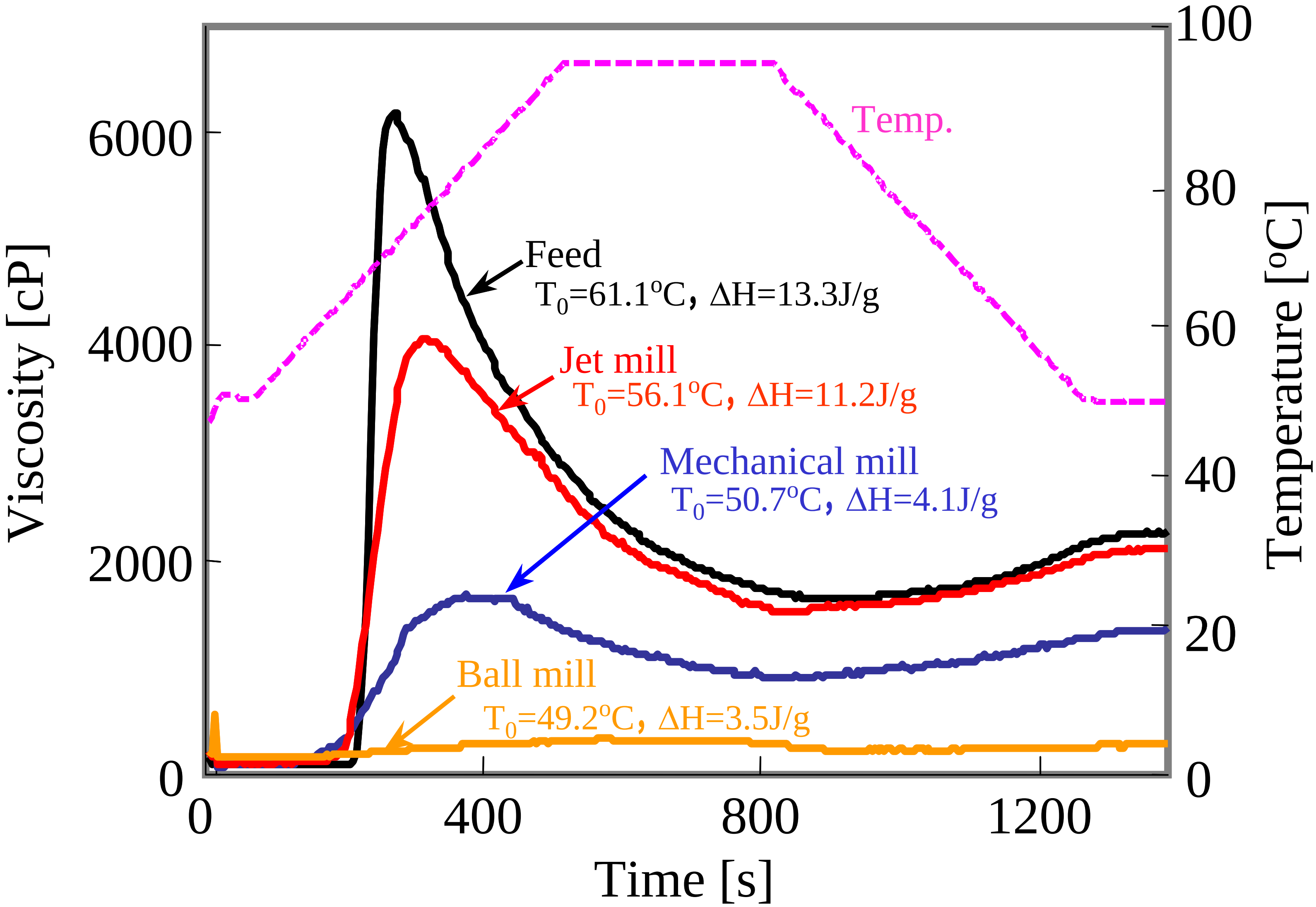
(d) Ball mill

SEM photos of potato starch particles ground in various mills

NISSHIN ENGINEERING



X-ray diffraction (XRD) patterns for potato starch particles ground in various mills



RVA (Rapid Visco Analyser) profile of potato starch particles ground in various mills

NISSHIN ENGINEERING

How to control color of powder by grinding

Material: Green tea

Method:

Grinding temperature and particle size

Type of mills: mechanical mill, jet mill, disc attrition mill

Measurement(color):

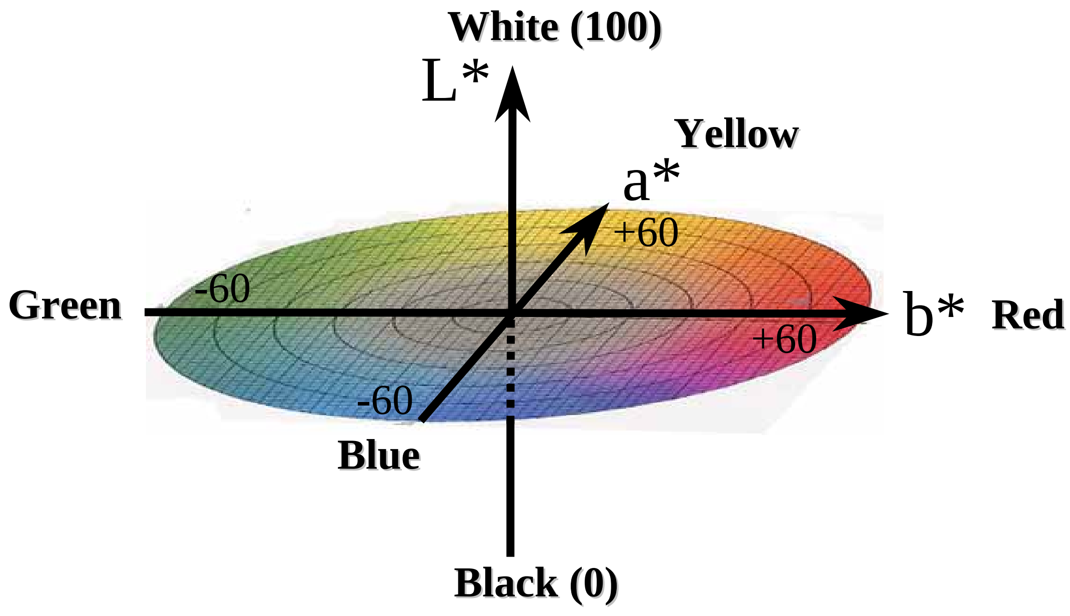
A tristimulus colorimeter CR-310 (Minolta)

Raw material
(leaves of green tea)

Ground product

NISSHIN ENGINEERING

CIE(International Committee on Illumination) L* a* b* color coordinates

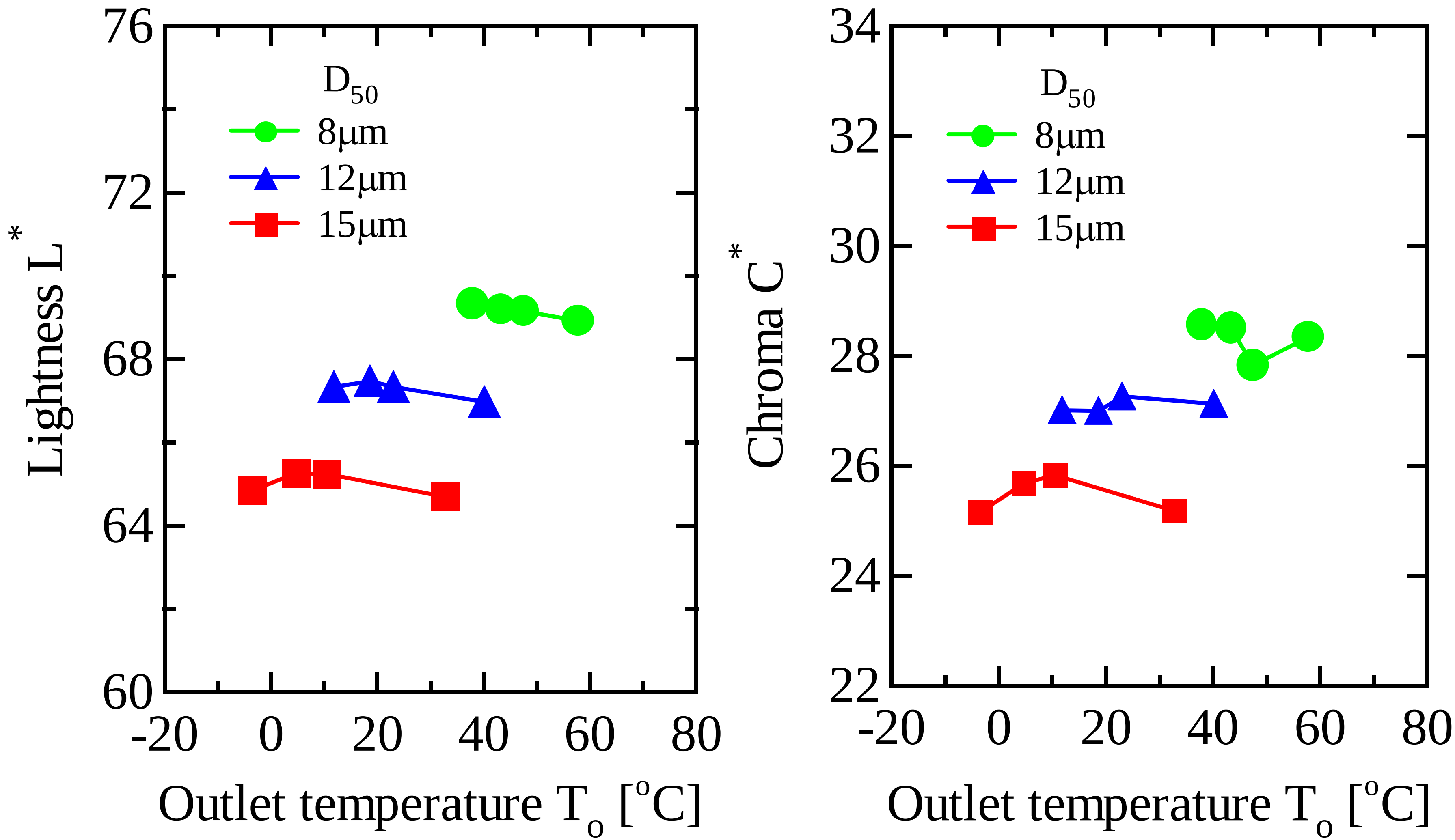


Chroma: $C^* = \sqrt{(a^*)^2 + (b^*)^2}$

L* : Lightness of a color

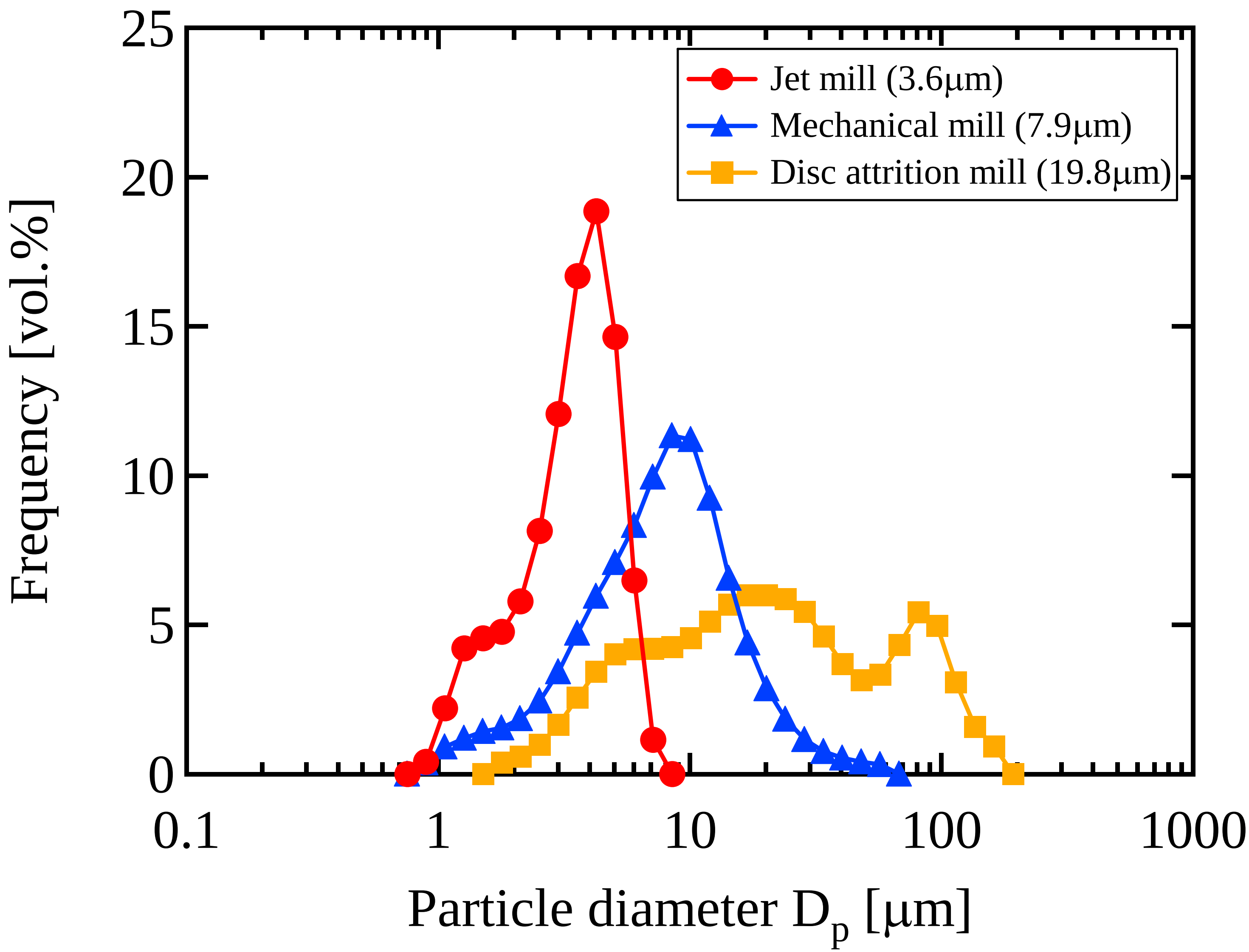
(ranges from black at 0 to white at 100)

C* : Chroma (color saturation or purity)



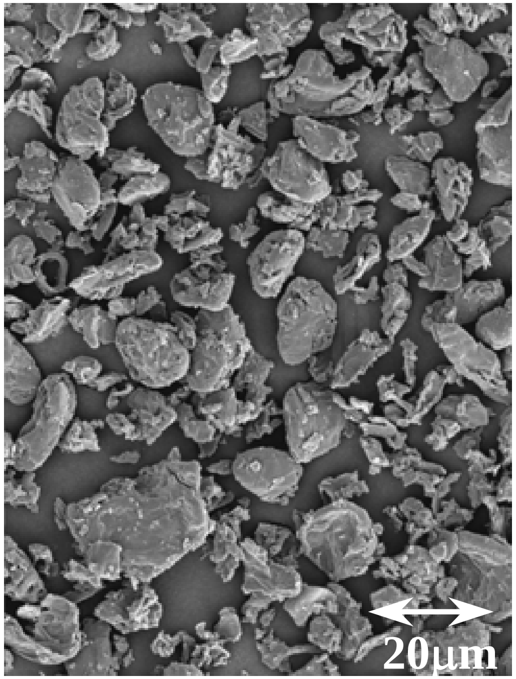
Effect of grinding temperature on color of green tea powder for various particle sizes

NISSHIN ENGINEERING

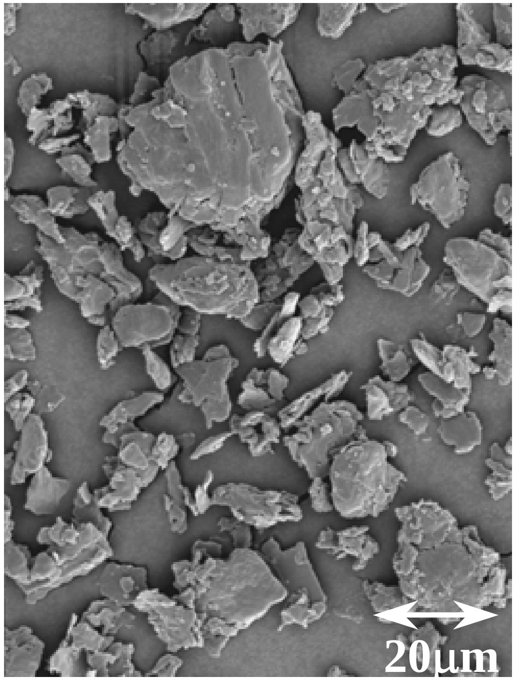


Particle size distributions of green tea powder ground in different types of mill

(a) Jet mill



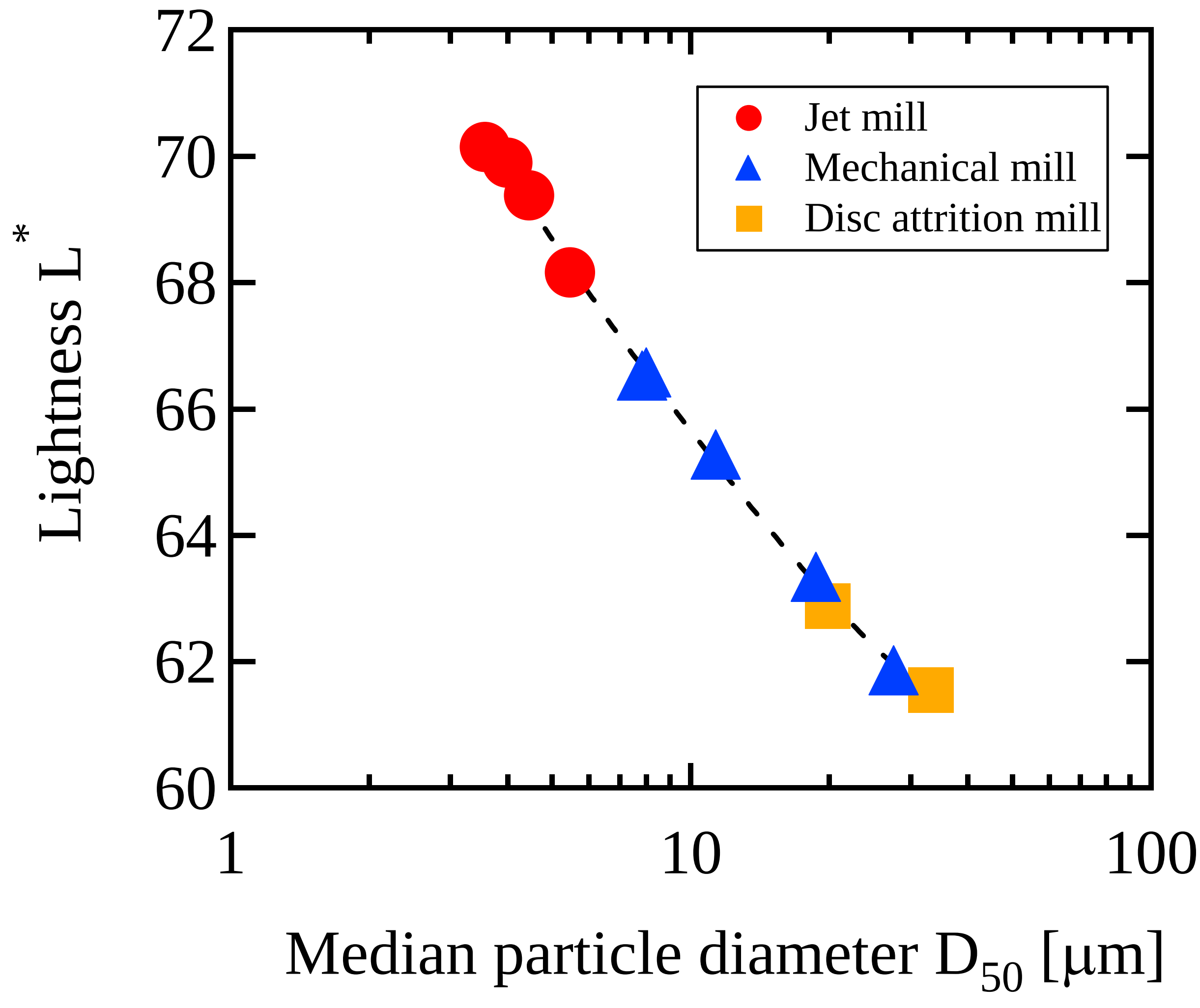
(b) Mechanical mill



(c) Disc attrition mill

SEM photos of green tea powder ground in various mills

NISSHIN ENGINEERING



Effect of particle size on color of green tea powder

How to control flavor of powder by grinding

Material: Buckwheat, green tea

Method:

Grinding temperature and particle size

Type of mills;mechanical mill, jet mill, disc attrition mill

Measurement (flavor):

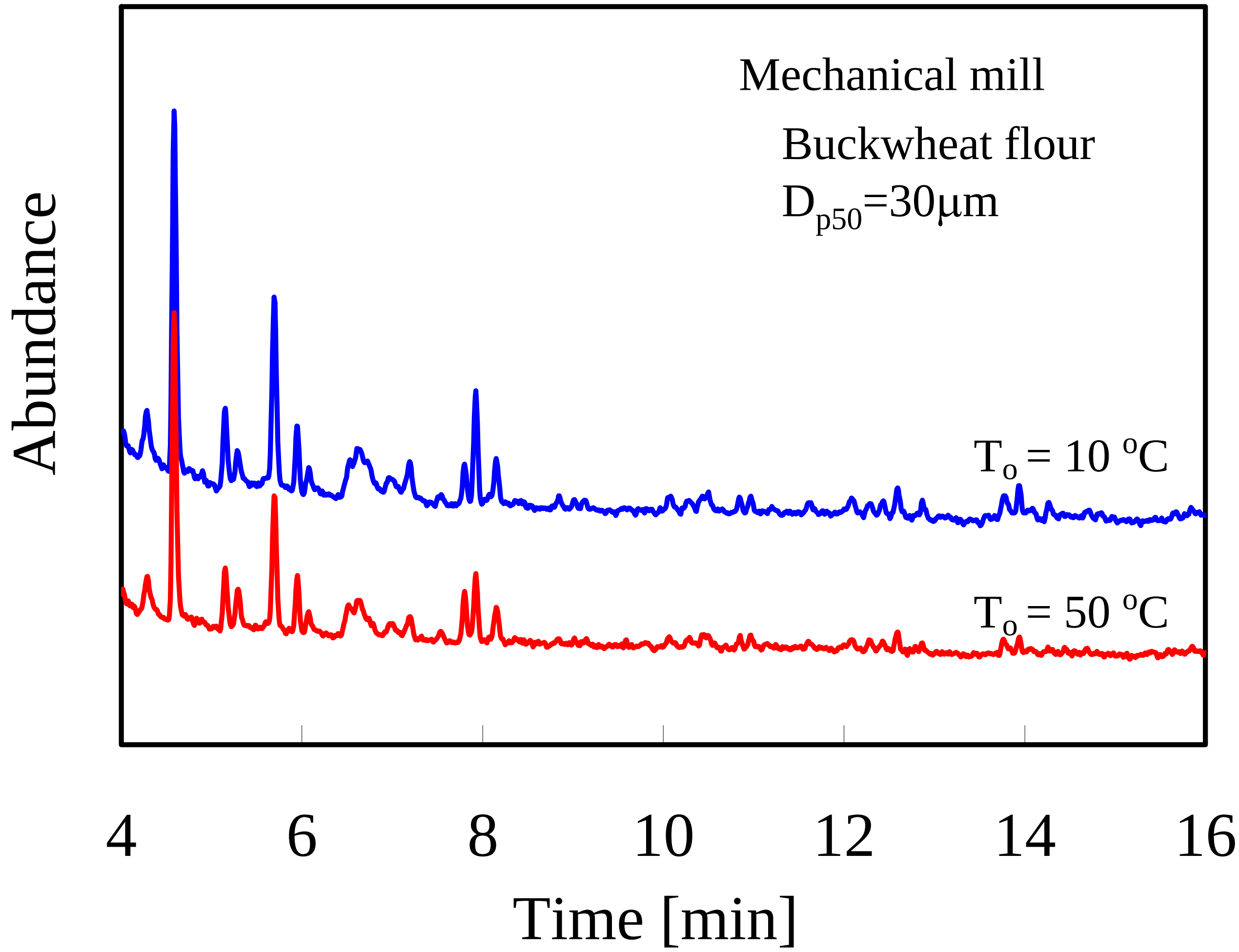
GC-MS(Gas Chromatograph-Mass Spectrometer) system:

GC-17A&QP-5000 (Shimazu, Japan)

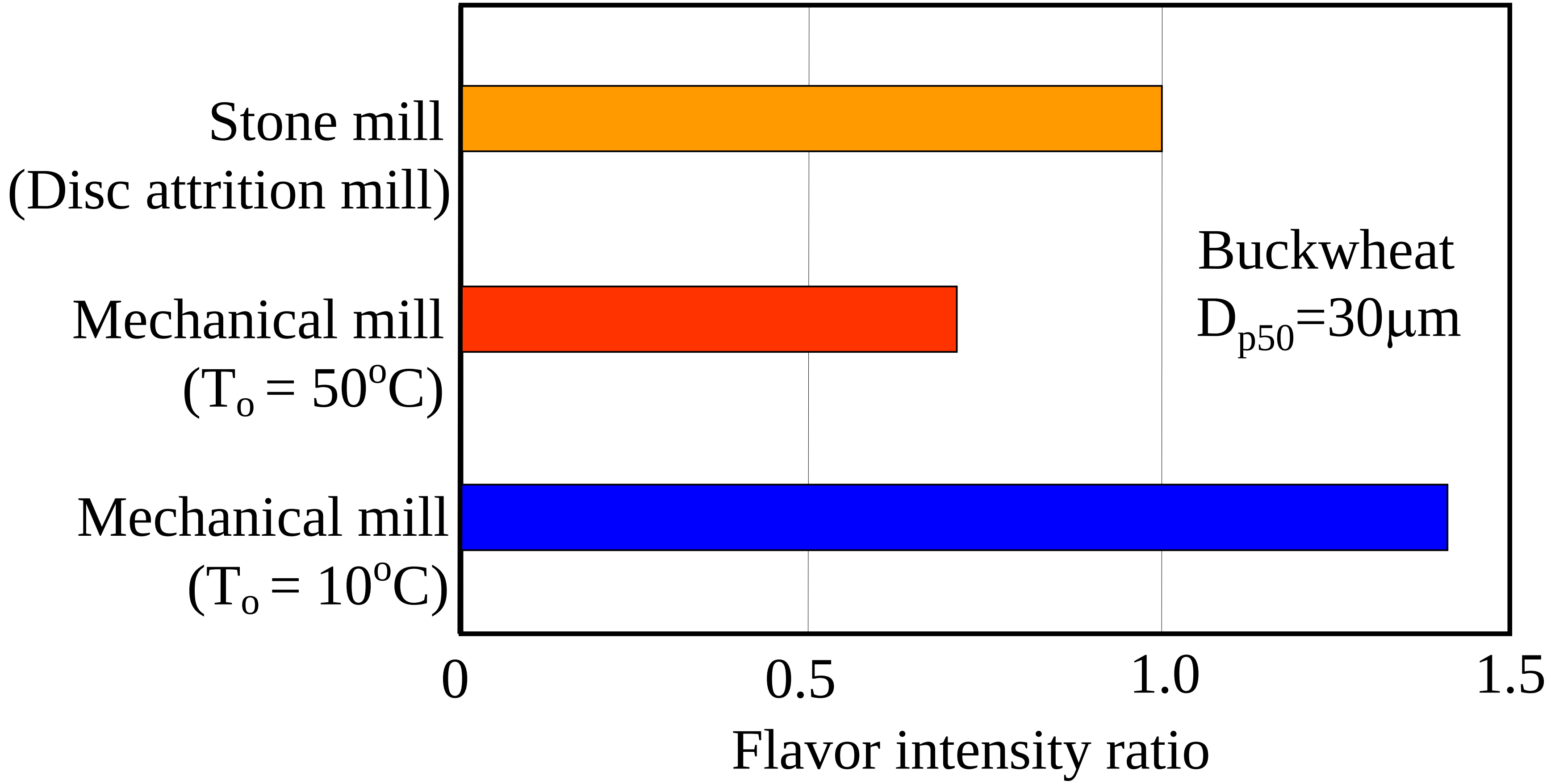
(a) Flowers (b) Husks (c) Grains (d) Flour

Buckwheat

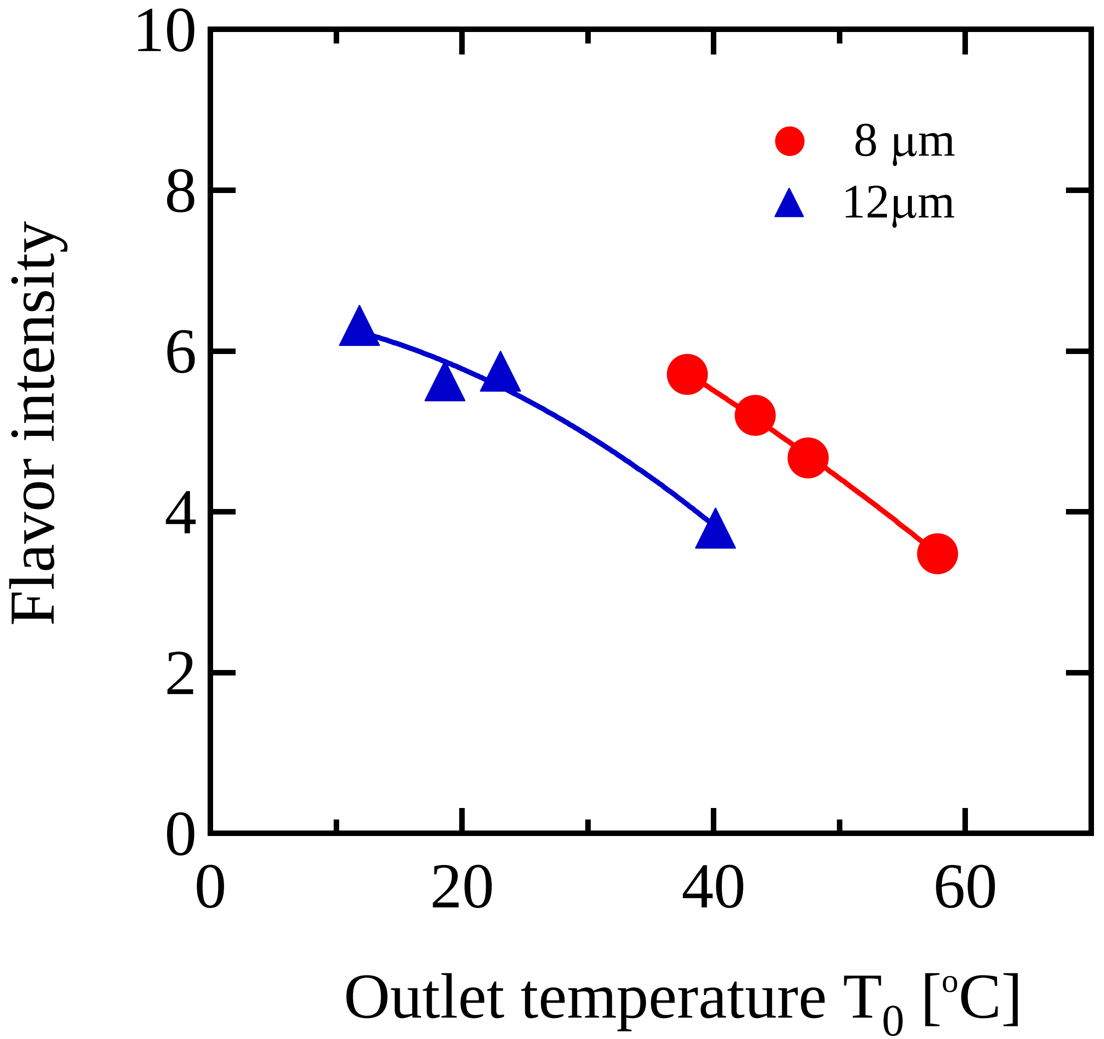
NISSHIN ENGINEERING



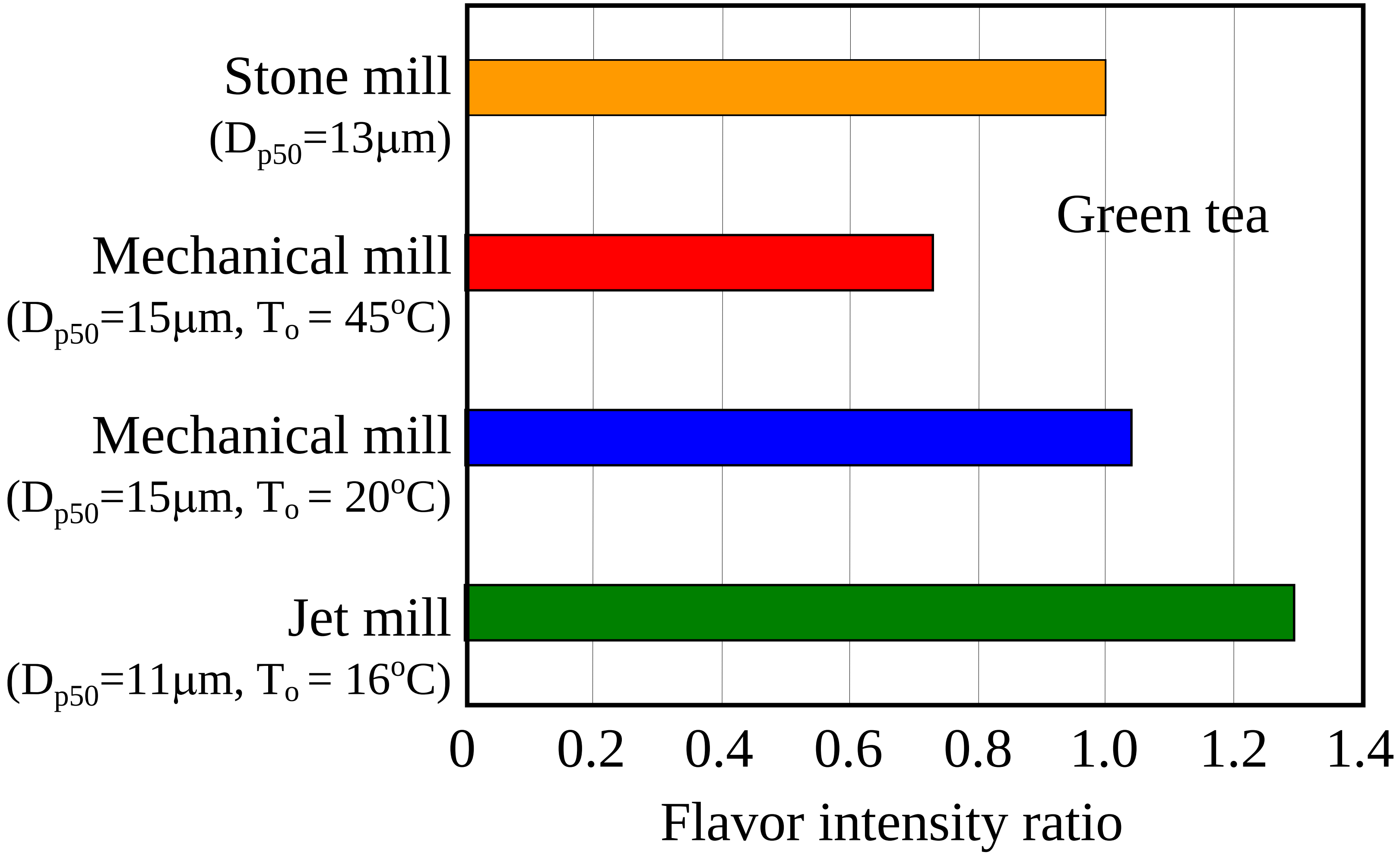
Example of Gas chromatogram for buckwheat flour ground in the mechanical mill



Effect of grinding temperature on flavor of buckwheat flour ground in the mechanical mill



Effect of grinding temperature and particle size on flavor intensity of green tea powder



Effect of type of mill on flavor of green tea powder

Conclusions

(1) The simulated impact energies are useful parameters for determining the optimum blade angle of the mechanical mill.

(2) The optimum blade angle for efficient changes in crystallinity of particles and pasting properties is different from that for size reduction.

(3) The particle size has a significant effect on color of powder. The grinding temperature and particle size influence flavor of powder.

(4) Types of mill strongly influence pasting properties of potato starch.